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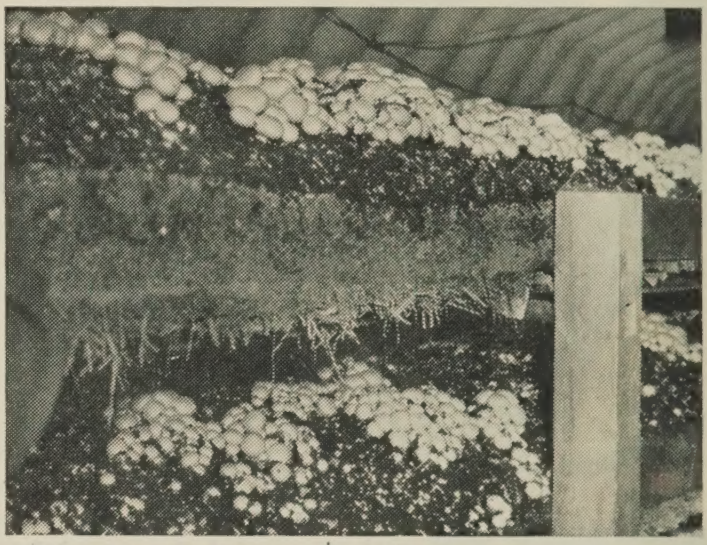

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MINISTRY OF
AGRICULTURE, FISHERIES AND FOOD

Mushroom Growing

Bulletin No. 34

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Foreword

At the time the sixth edition was published six years ago, and indeed before that, great changes and increasing specialization were taking place in the mushroom-growing industry, and they have proceeded apace during the past decade. The position now is that a number of specialist growers are developing their own techniques and refinements of growing practice, and it is beyond the scope of this Bulletin to attempt a comprehensive review of them. Furthermore, changes in practice are occurring so rapidly that no account can be reasonably up to date for very long.

In the light of these changes and new experience at home and abroad, this seventh edition has been completely rewritten. From the multiplicity of differences in method, an attempt has been made to give a picture of the principles of good house design and growing practice without describing any particular specialist's methods. This should help the less experienced grower to follow the principles and practice of the main systems of mushroom production, and to appreciate the advantages and disadvantages of each also the nature of the risks involved. The sections on diseases and pests have also been rewritten in the light of research and developments in methods of control. The Bulletin should prove a useful work of reference for every mushroom grower.

The Glasshouse Group of the National Agricultural Advisory Service, under the chairmanship of Mr. F. W. Toovey, Director of the Glasshouse Crops Research Institute, is responsible for this new edition. The Group wishes to thank specially the members of the Working Party (Miss D. G. Gandy, Messrs. P. B. Flegg, A. D. Harrison and B. D. Moreton) for their work in preparing the draft for publication, and the Glasshouse Crops Research Institute for help in providing so many of the new illustrations.

Ministry of Agriculture, Fisheries and Food
December, 1959

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General Considerations

In the recent past the cultivation of mushrooms was considered to be more or less a gamble, but experience and the knowledge of the cause of failures now make it possible to grow good crops with some degree of certainty. However, even the most experienced growers are liable to encounter unsolved problems, and the occurrence of baffling diseases and epidemics of insect pests may at times result in heavy losses.

Anyone intending to start commercial mushroom growing on his own account would be well advised to spend at least one year, either as a pupil or as an employee, on a holding of repute where the method of growing practised is that which he wishes to follow. Sound practical experience at the outset is undoubtedly a good investment, especially when it has to be recognized that a unit large enough to bring in a reasonable income will involve substantial outlay in buildings, equipment and materials for growing the crop.

A mushroom farm requires very little land; a farm of average size, including all ancillary buildings, need occupy less than one acre. However, there are certain points which should be borne in mind when choosing the site. It should be close to or adjoining a good road, as the basic materials of the mushroom grower — horse manure and straw — are heavy and bulky. Nearness to a town is desirable, because a source of labour is necessary for both heavy work in the composting shed and the lighter work of picking and packing. Most of the produce is usually sent to market by rail, and costs are reduced if the railway station is within easy reach.

On the site itself a mains supply of electricity and water is essential, and it is as well to make sure that these are near at hand before deciding to take over the land. In planning the layout of the buildings a gentle slope can be of great benefit if wisely used. Time and effort can be saved if the production line is so arranged that the compost is prepared at the top of the slope and moved down the gradient to the peak heating and growing houses. Time spent in planning the buildings to the best advantage can prevent waste of labour.

It is advisable to consult the proper authorities with regard to the development of the land and the interpretation of local byelaws which may apply. Some authorities will not allow large compost heaps to be sited near dwelling houses.

COSTS

Mushrooms can be grown in so many types of building that it follows that the cost of erecting or adapting buildings for this purpose must vary within wide limits. However, to look at the matter from the point of view of erecting, insulating, heating and lighting a new building for this purpose, the outlay would probably amount to 20–30*s*. per sq. ft of floor space. These figures are given as a very approximate guide, and it is sometimes possible to convert existing sheds or glasshouses at a much lower figure for the production of

mushrooms. Ancillary buildings would still have to be provided for, such as peak heating rooms, compost shed, office and stores.

The cost of growing a crop also varies considerably according to the size of the enterprise and the efficiency of management, a larger unit tending to have a lower cost of production per pound. Any production figures can only be approximate, but at the present time 2*s*. to 2*s*. 6*d*. per lb should reasonably cover the costs of production and marketing in a unit of moderate size. The labour required is difficult to estimate, but one man per 2,000 square feet of bed, cropped five or six times when trays are used and two or three times when mushrooms are grown on shelves, has proved a working basis on some farms.

The Cultivated Mushroom

THERE are many natural species of edible fungi in this country; by far the most popular is the Field Mushroom (*Psalliota* (*Agaricus*) *campestris*) with the Horse Mushroom (*P. arvensis*) probably a poor second. Normally, neither of these species is cultivated; indeed it is doubtful whether *P. campestris* is capable of producing a crop on composted horse manure. The cultivated mushroom of commerce is, perhaps, sufficiently distinct to justify regarding it as a separate species, and both *Psalliota hortensis* and *P. bispora* have been suggested, but so far there has not been any final agreement about its name.

From the grower's viewpoint there are two varieties, the white and the brown. Generally, the white variety is preferred by the public. A cream-coloured mushroom, which may be regarded as a light brown, is popular in a few markets. Spawn-makers select and propagate their own strains of these varieties.

There are three stages in the life cycle of a mushroom, (1) spores, (2) spawn (mycelium), and (3) mushroom. If a ripe mushroom is carefully removed from the ground, the white thread-like mycelium, resembling roots, can be seen at the base of the stalk and spreading in the ground. If the stem is cut off and the cap laid with the gills downwards on a sheet of clean white paper and left in still air for a day, a fine, brown powder will be found to have fallen from the gills. This consists of millions of minute spores of the mushroom which, under natural conditions, are carried by the wind, probably on to near-by grassland. When eaten by a horse, the spores, even after taking 2–4 days to pass through the animal's body, are believed to be capable of germination in the dung. Direct germination of the spores in the soil or on manure, without previous passage through the digestive system of an animal, can take place under natural conditions, but the development of mushrooms in pastures probably depends largely on surrounding conditions, including the amount of competition from other prevalent fungi.

Germination of the spores in dung leads to the formation of a mass of white fungus threads (mycelium) which permeate the dung. In the artificial culture of mushrooms, mycelium in the form of prepared spawn is introduced into a bed of composted horse manure. The mycelium fills the compost, and

also the thin casing layer of soil or peat which covers the bed, and in due course mushrooms arise from the surface of the bed.

The precise conditions which stimulate the development of the mushroom from the mycelium at the surface of the casing layer are not known. The field mushroom produces its buttons most profusely in the autumn, when the air has become cooler and more humid, and the soil surface is damp. Similar conditions also favour the production of buttons of the cultivated mushroom. It is also known, on the other hand, that mycelium can run at temperatures higher than the maximum at which cropping will take place.

Choice of Growing System

THERE are two main systems of growing mushrooms in use at the present time. They are usually called the Shelf system and the Tray or Two Zone system. Both appear to be equally popular, and there has been much controversy over their rival merits. Final choice of the system to be adopted rests with the grower, who may be influenced by personal preferences, or by purely local factors such as availability of labour, or the need to adapt existing buildings. Essentially the shelf system, which is the older of the two methods, entails the transfer of the prepared compost to shelves in the growing house. All subsequent cultural operations are carried out in the house. With the tray system the compost is packed into trays or boxes and stacked in a specially constructed room for peak heating (pasteurization) and spawn run. The trays are then moved into the cropping houses after they have been cased. The main characteristics of the two systems are summarized in Table I.

The shelves used are about 6–8 in. deep and 2–4 ft wide, and run almost the complete length of the house. There are usually three or four tiers of shelves with a space of 1½–2 ft between them. There should be a gangway on either side of each tier of shelves to facilitate cultural operations (see Plate VI).

The size of trays varies from 3–6 sq. ft but they may be considerably larger. After filling, they are stacked one on top of another in the peak heat room with about 1–2 in. of air space between. This is obtained by placing battens of wood on the edges of the trays, or by using specially designed trays having the ends higher than the sides. With close stacking the peak heat room need only be half the size of a cropping house, thus saving fuel during peak heating. It is possible to spawn the trays without restacking them, but it should be remembered that the growing spawn requires oxygen, which may be deficient if the trays are too closely stacked. It is therefore common practice for the boxes to be restacked, giving more room between them during spawning. Some of the larger mushroom farms have special spawn running rooms. When the compost is well occupied by mycelium, usually in 12–14 days, the trays are moved out of the peak heat room, cased and taken into the growing houses where they are stacked chequer-board fashion (see Plate VI); some support is needed for the end trays.

TABLE I

Comparison of Shelf and Tray Systems

Shelf	Tray
All growing houses must have insulation adequate for peak heating.	A specially constructed peak heat room is necessary. It can be about half the size of the growing houses which it serves. One peak heat room can serve three growing houses.
Strong timber supports and planks are needed for the shelves. If properly treated they will last for many years.	Second-hand fish boxes can be used, but they only last for a few crops. Specially constructed trays are more expensive and should be treated with preservative.
Prepared compost is moved once, when it is taken from the composting site to the house. Subsequent cultural operations are carried out in the house.	Trays are filled at the compost heap and moved into the peak heat room. They are stacked close together for peak heating but may require re-stacking at spawning. They are moved out of the peak heat room at casing time and restacked in the cropping house.
Little mechanization is possible in filling and emptying.	Roller conveyors and fork-lift trucks facilitate stacking and moving of trays.
Supplementary heating is required in the houses at peak heating.	Peak heat room must have adequate heating built in.
Up to three crops per year per house can be grown.	Up to five or six crops per year per house can be grown.
Beds usually have 8 in. of compost.	There are 4–6 in. of compost in trays. Less compost is required per crop than on shelves.
Average yield is 2–2½ lb per sq. ft per crop.	Average yield is 1¼–1½ lb per sq. ft per crop.
A good crop can be left in the house a little longer without disrupting the programme.	A very strict time table is necessary if five and a half crops are to be obtained in a year.
The house can be "cooked out" before emptying, to kill off pests and diseases.	"Cooking out" can only be carried out if the trays are taken back into the peak heat room, but this may not be available when it is wanted.
There is adequate time to disinfect the empty house before refilling.	Trays are frequently not sterilized between each crop. They are more difficult to clean than shelves.
A disease in the compost or casing can spread throughout a bed very rapidly.	A diseased tray can be removed or the crop destroyed *in situ*. There is less danger of disease spreading from tray to tray.

Adoption of the tray system means that the growing houses need not be so well insulated as in shelf growing. It is therefore useful for growing mushrooms in buildings which were not designed for the purpose, as the expense involved in adapting them is not so great. The peak heat room must, however, be properly constructed. As each crop remains in the growing house

for a much shorter period, it is possible to get five or six crops in a year in each house, but to obtain this number of crops per year a strict time-table must be operated, otherwise many of the advantages of the system are lost. The average crop in trays is smaller than in shelves, although the annual crop per house can be about the same under each system.

Since the introduction of the tray system from the U.S.A., growers have had ample opportunity of comparing the merits and demerits of the two systems. In recent years there has been a tendency for growers, whenever possible, to combine the best of both. Thus the use of larger trays is becoming popular, whilst greater mechanization can be introduced into shelf growing by having the shelves in movable sections which can be filled in the composting yard and carried into the house with a fork-lift truck. Trays of 10–20 sq. ft, with corner supports, are being stacked side by side and on top of each other to give the appearance of shelves (Plates VI–VII). In handling large trays and shelf sections mechanical aid is essential, but by these methods it is possible to combine a good peak heat with lower costs for growing houses, whilst still retaining the advantage of the bigger crops which are possible on shelves.

Mushrooms were originally cultivated on ridge beds laid on the ground. This method is still retained by some growers who crop in caves, mines or glasshouses (Plate VII). In these situations peak heating is not possible, but many such growers recognize the advantages and have built peak heat rooms and either crop in trays or peak heat the compost before making it into beds. In glasshouses a winter crop of mushrooms can be grown after the tomato crop has finished. The beds can either be made in ridges or on the flat. Flat beds are usually surrounded by a board or sheet of corrugated iron about 6–8 in. wide which helps to retain the compost and casing. Obviously the area cropped with floor beds is much less than can be obtained if the glasshouse is filled with trays or shelves.

Buildings

The successful cultivation of mushrooms on a commercial scale involves control of the environmental conditions, especially temperature and humidity, within fairly close limits. The ease or otherwise with which this can be achieved depends on the structure of the buildings and on the heating and ventilation systems. Although it is possible to adapt a wide variety of existing buildings to provide the necessary conditions, experience has proved the advantage of houses specially designed for the purpose.

In a building where mushrooms are to be grown it must be possible to maintain an air temperature of at least 55°F, preferably 70°F, against the coldest outside conditions. At some time during the growing process a temperature of about 120°–140°F is required in the houses if the shelf system is adopted, though for the tray system a building specially insulated and heated for this part of the procedure is used (see page 24). Obviously, to produce and maintain these conditions considerable attention must be paid to the construction of houses and precautions taken to economise in

fuel consumption. Advice on heating systems can be obtained through the National Agricultural Advisory Service.

MUSHROOM HOUSES

There is such a variety of designs and materials used in construction that it is not possible to describe them all here. Buildings may be constructed on the site, but prefabricated concrete and asbestos buildings are also widely used. It is therefore proposed to enumerate a few principles which should guide the grower in his choice of building.

Dimensions and Layout

When deciding on the size of the house the available supplies of manure and labour must be considered. It is highly desirable to be able to complete certain operations, such as filling the house with compost, in one day. There are many houses in use holding more than 4,000 sq. ft of cropping area, but the modern tendency is to build units of 1,000–2,000 sq. ft. It is advisable not to overcrowd the house, and it is recommended that for every 1,000 sq. ft of growing area there should be about 4,000–5,000 cu. ft of air space. Thus, irrespective of the growing system adopted, a given area of trays or shelves will require approximately the same size house; to reduce the ratio of bed area to air space tends to reduce yields, though the efficiency of the ventilating system obviously has some effect.

The modern growing house is between 40–60 ft long, 16–20 ft wide, and 8–9 ft from floor to ceiling or eaves. The shelves, if used, are usually arranged in three tiers on either side of a centre pathway which, together with the end doors, should be wide enough to take a truck or trolley (see Plate V). This simplifies filling and emptying the beds. Some older type houses have up to six tiers of shelves, and in order to operate the top tiers there is an upper deck about 6–7 ft from the floor.

With the tray system there is more latitude in the layout of the trays. There are no permanent fixtures, and the trays can be laid with intervening pathways either running down or across the house.

The mushroom does not need light, and windows are unnecessary. They also reduce the insulation value of the walls, and sunlight falling on developing mushrooms can cause a browning of the cap. Artificial light is quite satisfactory, and travelling inspection lamps are very useful in addition to fixed light. All wiring must be capable of resisting prolonged high humidity and temperature, particularly if peak heating is to be carried out in the building. The use of low voltage lighting systems has much to recommend it from the safety aspect.

Floors

There is no better floor than one of smooth finished concrete strong enough to bear the weight of trucks, shelving or trays, and preferably sloping away from the centre pathway to drainage gulleys at the sides of the house. The use of no-fines concrete in the floor base improves insulation. Steps involve extra work in moving materials in and out of the house and should be avoided. If the floor level of the house is above ground level, then a gently sloping ramp outside the door is necessary. Concrete pathways leading to the house greatly assist the maintenance of farm cleanliness.

Walls and Roof

The walls and roof, especially the internal surfaces, should be constructed with a minimum of rough joints, cracks or crevices which will harbour pests and diseases. Fumigation can never be effective unless these conditions are fulfilled.

Peak heat rooms, and growing houses in which peak heating is to be carried out, must be well insulated and constructed to withstand high temperature and humidity. For these, 11 in. cavity brickwork with the cavity filled with an insulation material such as fibre glass, rock wool or aluminium foil is satisfactory. The inside walls are frequently of breeze block, but a smooth waterproof finish is necessary as an aid to hygiene and to prevent the insulating material from becoming damp. A recent approach to the insulation problem at the Glasshouse Crops Research Institute, which is now the national centre for mushroom research, is to have outside walls of brick with internal ones of concrete blocks. Between the two are sheets of plastic-bonded fibre glass protected on both sides by polythene sheeting. This is a most effective method of insulation, but it is of course an expensive form of building.

Buildings in which peak heating is not contemplated may be constructed with rather less attention to insulation, but as it is becoming a routine practice to 'cook-out' the growing houses at the end of cropping at temperatures of 140°–160°F, the insulation in all houses must be of a high standard.

For the maintenance of normal cropping temperatures, a wide variety of materials and methods of construction may be used. A corrugated galvanized iron outer skin on wooden framework, with asbestos lining and rock wool or similar material between as insulation, is a common type of structure. Cavity walls built of breeze blocks and asbestos cement sheets are quite suitable for outside walls, and asbestos insulation board for inner walls. A considerable saving in materials can be effected if the buildings are erected with common walls between each house (see Plates II–III).

The roofing material may be corrugated asbestos-cement sheeting or roofing felt overlaying treated timber. Materials used for insulation of the walls are equally suitable for use in the roof, but it is important to ensure that moisture from the growing chamber is not allowed to condense in the insulation under the roof. Many houses have a false ceiling of asbestos cement or similar material, above which is laid the insulating medium, but this is not essential, and a flat roof properly insulated can be equally satisfactory. It may be desirable to have a slight slope on the ceiling to avoid condensation dripping on the beds.

The peak heating room required on a tray farm can be about half the size of the growing rooms which it will serve and must be insulated sufficiently for a temperature of about 130°F to be reached and maintained in the coldest weather. It must also be possible, when required, to keep the temperature below 75°F in hot weather. One peak heat room can serve at least three growing houses.

Ventilation

A regular supply of fresh air and even circulation of air within the house is needed. There is little precise information about the optimum environmental conditions for growing mushrooms, but there can be no doubt of the

ill effects of inadequate ventilation. During much of the year, while artificial heat is in use, requirements are usually met by ventilators at floor and roof levels; rising warm air passes out through the roof and fresh air is drawn in at floor level. Rising currents of warm air over heating pipes also create a circulation of air throughout the house. Under these conditions cool air entering a house is warmed and its relative humidity drops; this means there is a greater tendency for the beds to dry out, and it is common practice to damp the floors from time to time to counteract this. When the heating system is not in use, air circulation may be very sluggish and ventilation under these conditions will depend on wind or the use of fans.

Roof ventilators should be installed along the length of the house, in the ridge if there is one, and they may either open directly into the house or into the space between roof and ceiling, which then also requires to be fitted with vents. For maximum efficiency bottom ventilators should have a total area equal to that of the roof ventilators. Circulation is helped if they are spaced along the side walls, but if the houses are built in blocks, they will have to be in the end walls.

The use of fans is becoming more common and they may be fitted in the roof or in the end walls near the roof. A circulating fan in the centre gangway will help to dispel pockets of stagnant air between shelves or trays. Plastic ducting, connected to the ventilating fans and running the length of the house, is becoming increasingly popular since it is cheap, easy to instal, and outlet holes for the air can be made wherever they are needed. A more permanent type of ducting, fitted with outlet nozzles, can be made of metal, while ducting at floor level can be made in the concrete floor. The use of ducting improves the efficiency of the fans in air renewal and does much to eliminate pockets of stagnant air. Refinements to such a system include heating and humidification of the air before it enters the house.

Heating and Cooling Systems

The most common heating combination is a solid fuel boiler heating water which circulates in four-inch pipes. More efficient hot water heating can be obtained by forced circulation in small bore pipes. The use of oil-fired boilers and low pressure steam heating is becoming increasingly popular. Steam heating is particularly suitable for mushroom growing as it is possible to release 'live' steam into houses during peak heating. It is also useful as a means of humidifying the air during cropping and as an aid to sterilizing the house after emptying.

Coal or coke stoves installed inside growing rooms are not recommended. The heat is too localized, unless the stoves are specially jacketed, to give the best results. Oil stoves should not be employed inside the houses when the beds or trays are cropping because the fumes of mineral oil are harmful to the mushrooms.

Electrical heating by bar radiators is cheap to instal and efficient, but it is very costly to run. Attempts have been made to control the temperature of the beds by laying electric cables in or on them, but this method is expensive and not altogether satisfactory.

A few growers in this country have installed apparatus which gives partial air conditioning in the mushroom houses. A current of air is driven by a fan through a radiator or heating element and via openings in ducts or plastic

tubing into the house. In hot weather the radiators can be charged with cold water to cool the houses. On the whole, most attempts at cooling in summer have not been satisfactory or economic to run. Other methods which have been tried include pumping cold well water through radiators or using it to spray the walls of the houses. Passing air through ice compartments is another method of cooling but it needs a continuous supply of ice. Refrigeration apparatus to cope with the air of a whole farm is much too expensive to instal and would not be justified in a temperate climate.

Supplementary Heating

If peak heating is to be carried out in the growing houses some form of supplementary heating may be required (see page 25).

Shelving and Trays

Having built or adapted existing houses, the next major item of equipment is the shelving or trays in which the mushrooms will be grown.

Shelving. A variety of materials can be used to make shelving. Wood is most commonly used, but concrete, steel scaffolding and angle-iron have all been used with success. The material should be protected from decay or corrosion and strong enough to support the considerable weight of the compost and casing; it should also be easy to clean at the end of cropping.

The uprights are usually set in pairs about four feet apart down the length of the house. These are jointed by cross bearers, one for each tier of shelving. In a single storey house there are three or four tiers. The shelf bottom, usually consisting of loose wood planks, is laid on these bearers, together with the side boards, about 8 in. high, which retain the compost. It is permissible to have small gaps between the boards forming the shelf bottom, but they should not be wide enough to allow the compost to slip through. The shelves should not be more than 4 ft wide for convenience of working, and a space of about 2 ft between each shelf is needed as headroom. The bottom shelf should be set about 1 ft from the floor to allow room for sweeping out.

If wood is used it should be treated with a preservative. When creosote is used it should be of good quality* otherwise the fumes can be harmful. Even if this grade is used, care should be taken to allow time for weathering. Timber is much more liable to harbour pests and diseases than metal and must be thoroughly cleaned between crops. The wooden uprights which carry the whole weight of the shelving and bed must be strong. The weight of a mushroom bed, excluding the shelving, may be as much as 30 lb per sq. ft. The uprights and bearers should be constructed out of 4×2 in. timber at least. The boards for the shelving can be 6-8 in. wide by 1–1½ in. thick.

Metal is corroded by contact with compost and it is advisable to limit its use to supports and bearers only. Metal shelving also encourages the formation of a soggy layer of compost at the bottom of the bed. As an alternative to boards, the bottoms of shelves can be made of coarse wire netting over which a layer of kraft paper is placed.

* See British Standard No. 144 of 1954. Obtainable from British Standards Institution, British Standards House, 2 Park Street, London, W.1.

Reinforced concrete shelves have sometimes been used, but, as with metal shelving, the lower layers of the compost may become too wet.

Trays. The sizes and types of tray in use vary widely but all trays on a holding should be of the same size and design so as to be interchangeable. They are usually made of wood, sometimes with a heavy gauge wire mesh bottom which is covered with kraft paper when the trays are filled. The wire mesh is lighter than wood, but the cost of renewing paper has to be considered. Many kinds of second-hand wooden boxes, usually with a surface area of 4–8 sq. ft, such as fish boxes, are used with satisfactory results. There now seems to be a general trend towards larger, specially constructed trays of 6–20 sq. ft. Trays are not usually as deep as shelves, being about 5 in. deep at the sides and 6 in. at the ends. With mechanical aids for handling, bigger and deeper trays will probably become more popular.

The timber for trays should be at least $\frac{1}{2}$ in. thick and preferably thicker for the ends. Treatment with preservative increases the life of the timber, but some growers find that damage during handling is far greater than loss due to decay and consequently do not consider it worth while. If trays are specially made the corners should be reinforced with metal corner plates and corner posts. Posts not only strengthen the joints but also take the weight of the trays above in the stack. All nails should be galvanized.

Glasshouses

Glasshouses can be adapted to full-time use for mushroom growing. The outside is covered with a layer of fibre glass which is protected with roofing felt held firmly in position with wire netting. This makes an adequate building which can be converted to the growing of other glasshouse crops at short notice (see Plate III).

Owing to the difficulty of keeping an even temperature of about 60°F, unconverted glasshouses are most unsuitable for mushrooms in the summer months, but winter production is a common commercial practice. The walls and roof are lined with strips of hessian or kraft paper. The beds are laid down immediately the tomato crop is finished, i.e., in late August or September. The ground should first be treated with formaldehyde and an insecticide to prevent possible infestation of the compost. Usually floor beds are laid, with narrow intervening paths, but some growers instal shelving or use trays. Cropping begins in mid-October and ends in February, in time for the next crop of tomatoes to be planted out in March.

Since none of the diseases of mushrooms is known to affect tomatoes there is no reason from this particular standpoint why spent compost should not be used as a manure for this crop,* but there may be other problems in its use in glasshouses. It should also be realized that if infectious mushroom diseases have been present these may survive in the house until the next mushroom crop. If mushroom diseases are known to be present and it is intended to grow mushrooms the following winter, complete removal of the spent compost is advisable.

It must be remembered that if mushroom beds occupy the house through the winter there is insufficient time to carry out soil sterilization before planting tomatoes in March.

* In any case, some of the compost would have to be removed from the house, as the quantity in floor beds would be an excessive dressing for the tomato crop.

Sheds and other Buildings

Lightly constructed buildings with or without artificial heat, especially those without, should be provided with some form of insulation to avoid sudden changes in temperature. With sheds it is advisable to provide an inside lining with a 4 in. space between it and the outside wall. Asbestos-cement sheets are suitable for this purpose. Large buildings, such as disused stables and barns, often require attention so that draughts may be excluded. If there are windows, they should be fitted with rough shutters or screens to protect the beds from direct sunlight, but diffused light is not harmful.

Caves and Mines

These are not used extensively in this country, but they provide quite satisfactory growing conditions. However, the temperature in caves and mines is much lower than that employed in mushroom houses and the rate of cropping is correspondingly slower. Special attention should be paid to accessibility, for although it may be comparatively easy to carry compost into the cave or mine, it is sometimes more difficult to remove it. Trucks, for example, can easily be taken down a crooked sloping gallery, but it may require a special arrangement of the winch mechanism to bring them up again. Suitable ventilation, usually by means of shafts, and some means of coping with flooding or drip water are essential if underground sites are used. Traditionally, mushrooms are grown in ridge beds and no peak heating is carried out, but in recent years cave growers have begun to build peak heat rooms where the compost can be treated before being made into beds. Tray culture is also becoming popular in caves where site contamination has become a serious problem.

Ancillary Buildings

A composting shed, whilst not absolutely essential, is most desirable. It affords valuable protection to both compost and workers in wet and windy weather. Variations in the quality of different lots of compost, caused by chilling or soaking, can be eliminated. The composting shed need only be an open-sided building with a roof sufficiently high to permit the rapid escape of steam during turning and the use of machinery such as compost turners, fork-lift trucks and tractors. The floor should be of well-finished concrete to minimize the risk of infection from the ground and to facilitate the use of machinery. As an added refinement the floor can have a drainage system which enables the liquid draining off from the compost to be collected and sprayed back on to the heap. Added protection from the wind and rain can be obtained by filling in the sides of the shed with walls of straw bales (see Plate I).

A shed for the storage and preparation of casing material is also desirable. If casing materials are kept in the open there is a considerable risk of their becoming contaminated by airborne diseases. If peat is used for casing, a tank should be built for soaking it. This tank should, if possible, be large enough to contain all the peat needed to case a complete house. A concrete floor is necessary for mixing the ingredients.

A packing shed is necessary as well as a general store for tools, chips, etc., and these should be sited in a central position to cut down unnecessary walking.

Composting

MUSHROOM mycelium can grow in fresh uncomposted horse manure, but many other fungi are also present and will compete for the available food material. Fresh horse manure readily heats up, and a temperature is soon reached at which the mycelium is killed. The composting process results in the loss of the more readily available nutrients and reduces the number of micro-organisms that can live on the remaining material. Pre-heating compost in this manner before use results in a medium in which the mushroom mycelium can flourish, and which is reasonably free from trouble from competing organisms, and has its temperature under control.

MATERIALS

The traditional basic starting material, fresh manure from horses bedded on wheat straw, is still widely used although supplies are less plentiful than in the past. Much has been written on the effect of the food which the horses eat on the type of manure produced. While such factors may well affect the value of the manure for mushroom growing the supply position is such that, today, mushroom growers cannot be selective, but must make the best use of whatever manure is delivered. In view of the gradual reduction in the quantity of horse manure, several so-called synthetic composts have been developed utilizing cereal straw and similar materials to which activators are added. These synthetic composts are now proved to be a commercial proposition, though they have not been widely adopted by mushroom growers.

Much of the horse manure at present available is from racing and riding stables and tends to be deficient in droppings. As a result it is common practice to boost it with such materials as poultry or pig manure, fertilizers, and activators of the type used for making synthetic composts.

COMPOSTING SITE

The most important feature of the composting site is a sufficiently large surface of smooth concrete upon which to carry out all the composting operations. Concrete flooring allows thorough cleaning before a stack is built and after it has been filled into the house. A slight slope to the floor makes washing down much easier, and evil-smelling pools of liquid do not collect during composting. The approaches to the composting area should also be of concrete, thus making it possible to extend effective cleaning operations. Cover and protection from wind and rain, although not essential, are advisable (see page 11).

The composting site should be large enough to take the maximum number of stacks likely to be in preparation at one time, and also large enough for the storage of manure and straw for use in composting. Easy access for delivery lorries and the trucks used for filling the houses is also important.

COMPOSTING PROCESS

The replies to a questionnaire circulated by the Glasshouse Crops Research Institute in 1957 indicated that there are almost as many methods of preparing mushroom compost as there are growers. Nevertheless, there are some basic underlying principles, although in practice each grower tends to develop a method suited to his experience and the conditions on his farm. It is proposed, therefore, to describe the composting process in general terms and to try to indicate the variations in procedure which take place.

Whatever method is employed, the basic requirements are that:

(a) the starting material should contain sufficient nitrogen in utilizable form,

(b) during composting the stack should be adequately aerated, and

(c) sufficient water should be applied.

A nitrogen content of 2 per cent on a dry matter basis is recommended, possibly a little lower if a short period of composting in the stack is intended. Aeration and mixing of the stack is ensured by turning it at frequent intervals. Water is applied when the stack is first made, and further additions of water may be necessary at each turn of the compost. The quantity of water required decreases as the compost reaches readiness for filling.

Many differences in actual procedure are found. The traditional method consists in turning the horse manure stack at weekly intervals for four or five weeks followed by a process known as peak heating. This involves heating the compost in a special room or in the growing houses to a temperature of 130°–140°F for several days. Nowadays there is a general tendency to reduce the period of composting to about three weeks.

Many growers practice what is known as short composting; this may involve a composting period of about 7–14 days with the interval between turns ranging from as little as one day up to about four days. This is followed by peak heating for about seven days, during which further fermentation takes place.

HORSE MANURE COMPOSTS

Quantities and Quality of Manure

For practical purposes at least 1–2 tons of manure should be available for composting; if the stack is too small there may be difficulty in getting it to heat up or in preventing excessive drying out. Approximately 15 tons of manure or about half this quantity of dry racing stable manure, containing plenty of droppings, will be needed for 1,000 sq. ft of shelf beds, and this will make a stack about 9 ft wide, 5 ft high and 30 ft long. About half these quantities are required for 1,000 sq. ft in trays.

If the proportion of straw in the manure is excessive, so that the droppings are hard to find (e.g., with some racing stable manure), a nitrogenous fertilizer is needed to boost the compost, and such materials as poultry manure, pig manure, dried blood, urea, activated sludge or sulphate of ammonia can be used. The amount required depends on the state of the compost and the nitrogen content of the additive, e.g., materials such as dried blood, urea and sulphate of ammonia are added at the rate of 28–112 lb per ton of fresh manure, and poultry manure is sometimes added at rates of

up to 2–3 cwt per ton. In France, a method of composting has been developed in which the bulk of the manure is increased by the addition of an equal proportion of straw. This is a useful practice when manure is scarce or expensive and straw relatively cheap, but extra nitrogen must be given. Manure which is deficient in straw and has a soggy appearance can be improved by the addition of straw; wheat straw is generally used and should be thoroughly wetted before mixing, but under these circumstances extra nitrogen should not be necessary. It is difficult to recommend definite quantities of either straw or boosting materials to add to the original manure, but the finished stack should have an approximate density of 1 ton per 80–90 cu. ft.

Rasmussen, in Denmark, has carried out a considerable amount of work on the improvement of composts and as a result the following supplements have been found to be very satisfactory. To give the best results, these chemicals, as indeed all additions to compost, should be spread evenly throughout the stack.

Supplements per ton of fresh manure (after Rasmussen)

Material	*lb/ton*	*When added*
Sulphate of ammonia	15·5	at stacking
Calcium carbonate	57·7	at first turn
Gypsum	57·7	at second turn
Superphosphate	15·5	do.

Stacking

When sufficient manure has been delivered composting can begin; it is undesirable to have heaps of manure waiting for any length of time. Making the compost heap from fresh manure is known as stacking. The manure is shaken up by fork or with the aid of one of the many types of composting machine now available. It is at this stage that straw or the nitrogenous boosters, already described, are mixed in with the manure; no nitrogenous material should be added after stacking. Even mixing is most important. At the same time all extraneous materials such as salt licks, horse shoes, nails, glass, bricks, etc., should be removed, and large lumps of droppings broken up and evenly distributed. The shaken manure is then carefully stacked, each forkful being placed in position so that the stack is evenly packed. Very little trampling should be necessary. If the manure is dry, water is added from a hose pipe fitted with a rose; some composting machines have automatic watering devices. The objective is to wet the straw with the minimum of seepage from the stack.

The size and shape of the stack are important, as too large a surface area relative to volume leads to excessive drying out and cooling. The stack should not exceed 5–6 ft in height, and a width of 8–9 ft is common. The length depends on the quantity of material in the stack and the amount of room on the composting site.

The stack will begin to heat up, giving off steam and ammonia, and the temperature in the middle of the stack should reach about 140–160 F within a few days.

Turning

After about 5–7 days the stack should be turned. This is known as the first turn, and subsequent turns as the second, third, and so on. Turning

consists of systematically taking the stack apart, shaking up the manure, and re-stacking in another place. This ensures aeration and further mixing of the manure, and it also provides an opportunity to add water if necessary. If turning is carried out by hand the various sections of the stack can be re-arranged, the top and centre becoming the bottom part of the new stack and the original bottom being placed on top. This makes certain that the parts of the stack which were inevitably subject to anaerobic conditions are now placed so that they are adequately aerated. If this is carried out at each turn every part of the stack at one stage or another undergoes aerobic fermentation. This type of fermentation is generally believed to be the most desirable, though some hold the view that a certain amount of anaerobic fermentation is beneficial. When composting machines are used careful separation of the various parts of the stack is sometimes less easy, but the advantages of using a machine far outweigh this disadvantage.

At this stage the compost steams freely and has a strong smell of ammonia. If the compost has a greasy feel when handled, gypsum should be added at the rate of about 28 lb per ton of compost. The greasiness is due to an excess of sodium and potassium in the compost, which can be corrected by the use of a calcium salt, gypsum being the most suitable. This practice has done much to improve the quality of mushroom composts, since spawn run in greasy composts is usually very poor. Probably the best time to add the gypsum is at the initial stacking, with a further 28 lb per ton added just before filling the beds. Ground gypsum may be pink, white or grey, but they are all equally effective. Many growers add gypsum as a routine measure to guard against greasiness, and this is to be highly recommended.

As the stack is turned, large solid lumps should be broken up, and water applied to the dry areas. In parts of the stack where fermentation has caused overheating a dry white-grey patch is frequently observed. This is known as fire fang (said to be caused by *Actinomycetes*). It is not harmful, but the patch should be rewetted and mixed into the new stack. If the compost stack received sufficient water at stacking very little water should be required at subsequent turns. Large quantities at the later stages of composting cool the heap excessively and interrupt the composting process. When the first turn is complete the stack is again left to ferment, and subsequent turns are given at approximately weekly intervals until the compost has been in the stack for about 4 to 5 weeks, by which time the compost should be ready to transfer to the growing or peak heating rooms. The procedure at each turn should be the same as at the first turn, with adequate shaking and rearrangement of the stack. Using this method of composting the total period from stacking to filling is about 20–28 days.

Characteristics of a Good Compost

There are several ways in which the experienced grower can judge the state of his compost. A good compost made from horse manure should be brown, with a distinctive but inoffensive smell. If the compost is not quite ready for use ammonia may still be present and readily detected. This is not necessarily a bad sign as it will disappear during the peak heating process. The droppings should be in small fragments and evenly distributed, giving the compost a uniform appearance. The straw should be short in length and should have lost its stiffness and resistance to shearing and pulling. It should

readily fall to pieces in fine threads when rolled between the fingers. When rubbed between the fingers there should be no feel of greasiness. When squeezed in the hand, it should be moist enough to hold together yet break up readily afterwards, and the hand should be left moist but without pressing any liquid out between the fingers. A handful of compost when twisted with the hands should come apart readily without much effort. Some of these simple tests are shown in Plate IV.

If, as a result of these tests, the compost is judged to be undercomposted, a further period of composting is necessary with an additional turn at the end. This can in some circumstances be avoided by peak heating for a period rather longer than normal, but the beginner is advised to rely on composting in the stack. Dry compost should be wetted, and excessively wet compost given an additional amount of gypsum before continuing composting for another week. Some of the excess water can be removed during peak heating, but to do this care and experience is needed. The moisture content as determined by analysis at this stage varies from about 60–75 per cent, but in fact the hand test previously described is a better way of judging the wetness of the compost. Analytical methods for determining more reliably the suitability of the compost have not yet been devised, but the apparently rather crude methods just described have been in use for many years and with a little experience are quite satisfactory. The main need is to judge whether the physical condition of the compost is satisfactory; otherwise spawn growth and yield will be poor whatever chemical requirements may have been supplied.

Measurement of pH has often been recommended as a guide to the state of maturity and suitability of mushroom composts, but the difficulties of accurate measurement and interpretation of the results are too great to place any reliance on this method. The range of pH values favourable for mushroom growth is about 6·0–8·0, and compost properly prepared should fall within this range. The value of pH measurements in the peak heating process will be discussed later. As far as the composting process is concerned the grower would be well advised to ignore pH values.

SYNTHETIC COMPOSTS

Materials

Proprietary composts or materials for making composts without horse manure have been available for many years. The increasing shortage of suitable horse manure immediately after World War II led to research on mushroom composts, and a formula for making compost from wheat straw and standard fertilizers was developed by the Mushroom Research Association at Yaxley. The compost, known as M.R.A. synthetic compost, has proved commercially successful on several farms, some using it exclusively with very satisfactory results. The increase in the amount of racing stable manure since 1945 has, however, reduced the demand for a synthetic compost, but as a result of this work the industry is no longer completely dependent on horse manure as a source of compost. Several other synthetic composts are in fairly widespread use, particularly in the U.S.A., but these generally make use of materials not easily obtainable here.

The main basic materials of the M.R.A. synthetic compost are wheat straw, dried blood, together with superphosphate, gypsum, carbonate of

lime, sulphate of potash and trace elements. The formulae of the activators used in this compost are given below; they are obtainable ready mixed from several suppliers as M.R.A. Activator Nos. 1 and 2.

M.R.A. Activators
Ingredients per ton of wheat straw (unwetted)

M.R.A. Activator No. 1

Dried blood (12 per cent N)*	3 cwt	Aluminium sulphate	2½ oz
Superphosphate (18 per cent P_2O_5)	14 lb	Copper sulphate	2½ oz
Gypsum	35 lb	Boric acid	1¼ oz
Sulphate of potash	14 lb	Zinc sulphate	1¼ oz
Carbonate of lime	50 lb	Ammonium molybdate	1¼ oz
Manganese sulphate	12 oz	Chromium sulphate	½ oz
Iron sulphate	12 oz		

M.R.A. Activator No. 2

Superphosphate	14 lb	Potassium bromide	¼ oz
Gypsum	70 lb	Potassium iodide	¼ oz

Although the procedure for making this type of compost differs in detail from horse manure composting, the general principles of adequate aeration, water and nitrogen content still apply.

Preparing the Straw

The amount of straw required to fill 1,000 sq. ft of bed is about 3 tons (dry), or 4 tons if it has weathered for some time. Wheat straw is the most suitable: it should not be mouldy or decayed to any great extent, and some growers prefer long straw. Barley straw can be used, but without care and experience it may produce a soggy compost of poor physical condition. Some growers have difficulty in composting the modern hard-wheat straws now being grown on an increasing scale. A satisfactory solution to this problem is still awaited, but users of synthetic compost may find it advisable to use a mixture of barley and wheat straw. A mixture of half-and-half wheat and barley straw should be quite suitable.

The first essential operation is to wet the straw very thoroughly. This can be surprisingly difficult, but it is important because dry straw is very resistant to decomposition by composting. A very effective method of wetting baled straw, devised in the course of work at Yaxley, is to lay the bales two or three deep in a long row and let water drip slowly on to the straw from a drip pipe. This is a horizontal pipe supplied with water either at one end or in the centre, and has holes drilled along the top at about 3 in. intervals. The pipe must be absolutely level so that water drips evenly and slowly along its entire length. Such a device will wet a row of bales in 2–3 days much more effectively than by the application of large volumes of water. An alternative method is to lay the bales two deep in the form of a solid square or rectangle, and to apply the water with a rotating lawn sprinkler. On one farm, straw wetting is carried out in a building with nozzles spraying water from the roof. Recirculation of the water is sometimes desirable, for excessive losses of potassium can occur by constant leaching of the straw.

* If the percentage nitrogen (N) is different, add 28 lb more blood for each decrease of 1 per cent, or deduct 28 lb blood for each increase of 1 per cent in nitrogen (N).

It is advisable to allow the bales to heat up after being saturated. This helps to remove the shiny resistant outer coating of the straw and makes breakdown easier in the compost heap. The water should be turned on again for a day or so, just before making the heap, to ensure that the straw is thoroughly wet. This whole process requires up to seven days to complete, perhaps longer if the straw is slow to heat up. Barley straw should be wetted in the same way but should not be allowed to heat up to any extent as this softens it too quickly.

The straw should feel wet when stacked and, if necessary, it should be watered with a hose fitted with a medium spray during the breaking up of the bales.

Stacking

A stack for 1,000 sq. ft of bed is about 10 ft wide and 30 ft long, rising to a height of 4 ft. The area to be taken up by the stack should first be marked out by a wall of dry straw bales, and a layer of wet straw, previously wetted and shaken up, is laid out to a depth of about 9–18 in. If the area is too large for convenient working it can be split up into suitable portions and the stack constructed in say, halves or quarters. According to the weight of straw laid down in the first layer, estimated from the number of bales used, the appropriate quantity of Activator No. 1 is sprinkled evenly over the surface. The formulae given above show the quantities of ingredients needed for one ton of dry straw. A further layer of straw is laid on top of this, followed by a sprinkling of the appropriate quantity of activator. This sandwich process is continued until the stack is complete.

The labour needed can be reduced by the use of composting machines and a straw cutter. Straw should not be cut into too short lengths; about 6–12 in. is the most suitable length for handling and packing into the stack. As each layer of straw is laid down it should be trampled firmly but not too heavily (see Plate I).

The stack is now left to ferment and should soon heat up to over 130°F. The surrounding wall of straw bales gives protection from the wind, which is even more essential with this type of compost than with horse manure composts. The main bulk of the heap is straw, which is a light and springy material, and cold winds can easily penetrate the stack if no protection is afforded.

Turning

As in the horse manure process, the heap is turned at regular intervals of about 5–7 days, care being taken at each turn to shake up each forkful and to move the compost around in the usual way so that each part goes through each position in the heap. As the stack decreases in bulk during composting it can be made a little shorter and a little narrower at each turn. The parts of the stack which have dried out should be well watered, but every effort should be made to get the right amount of water in during the earlier turns. The later water is added, the greater is the risk of misjudging the amount needed.

At the last turn (usually four turns should be sufficient), the required amount of Activator No. 2 is sprinkled evenly throughout the heap. Gypsum is included in this activator and no more should be necessary. The compost is ready for use after about 20–28 days composting.

In appearance M.R.A. synthetic compost differs considerably from horse manure compost. There are no droppings, and at equivalent stages of development the synthetic appears to be less decomposed. It can also be made wetter than horse manure compost, containing up to 75–80 per cent moisture, without ill effects. Despite the differences in colour, appearance and texture, the same physical tests of the state of readiness of the compost already described can be applied.

After filling, the compost should be peak heated, as with compost made with horse manure. The surface of the beds may dry out almost completely, but this does not seem to interfere with cropping. Watering the surface of the compost between filling and casing is not necessary, in fact it may be harmful.

Synthetic compost made in this way has been shown, on a commercial scale, to be a complete and satisfactory alternative to horse manure compost. However, the use of synthetic compost does not make mushroom growing any easier, nor is there any extra freedom from pests or diseases. The compost, whatever the source of material, is in the hands of the grower, and synthetic composts can be spoiled just as easily as those made from horse manure. At present day prices, synthetic compost is no cheaper than horse manure. Experiments with urea in place of dried blood have shown that it is a satisfactory nitrogen source, and its use allows a considerable reduction in the cost of activators. Unfortunately, when urea is used instead of dried blood, the evolution of ammonia in the early stages of composting can be overpowering. Based on the M.R.A. formula, an activator made from activated sludge is now on the market as an alternative to M.R.A. Activator No. 1, and is somewhat cheaper. Both M.R.A. Activator No. 1 and activated sludge are used extensively to boost the nitrogen content of strawy horse manure.

The main advantage of synthetic compost is that it can be made on any chosen day from materials already in store. There need be no delays due to temporary shortages or delivery difficulties as may happen with horse manure, and it makes possible a product of a uniformity which, in practice, can rarely be attained with horse manure.

SHORT COMPOSTING

The terms 'long' and 'short' are applied to manure, straw and compost in ways which are frequently misunderstood. When applied to manure the terms usually describe the degree of decomposition: long manure is relatively fresh and the straw in it practically undecomposed, whereas short manure is well rotted and the straw very much changed in physical condition. These terms can also be similarly applied to both straw and compost, but much more usually the mushroom grower uses the term to refer to the length of the individual straws on the one hand, or the length of the composting process on the other. Thus straw is described as long when it is practically full length as a result of cutting by binder. Straw is 'short' when it has been combined or chopped so that it is less than about 6 in. in length.

When applied to mushroom composts the terms usually refer to the length of the composting period, but it is rather difficult to draw a hard and fast line in practice since the dividing line between long and short composting is not clear cut. The processes described so far are undoubtedly 'long' or

traditional composting methods. In the 1957 survey carried out by the Glasshouse Crops Research Institute it was decided to make an arbitrary division and to define short composts as those which were in the stack for a period not exceeding 14 days.

The development of the short-composting process was carried out in the U.S.A., and its success and popularity in that country is due mainly to the work of Dr. J. W. Sinden. The longer composting processes are rather wasteful of material, and in recent years efforts have been made to produce a suitable compost without the losses involved through lengthy periods in the stack. These efforts have been so successful that it is now possible to prepare a good compost with less than a week of composting in the stack.

There are two phases to the process. In phase 1, as it is called, the manure is thoroughly wetted before stacking but without excessive leaching. During the preliminary stages the manure is stored in rectangular piles up to 6 ft high and 6 ft wide. During the actual composting period of 7–10 days the stack is turned, with intervals of 1–3 days between turns, partly to mix and partly to aerate and loosen it. Many growers in Britain, possibly over a third, now use a short composting process with intervals between turns of 2–3 days.

It is most important to get rapid fermentation. This is done by having a stack with a loosely packed core which ensures aerobic composting, whilst at the same time the sides are more tightly packed to retain heat. Dimensions of the stack vary therefore according to circumstances. For instance, in summer, when heat losses are less, the stack can be narrower than in winter, and raw, strawy manure can be made into wider stacks than well decomposed manure.

The next stage in the process, phase 2, is very similar to the peak heating process which is described in the next section (see page 24). In the short-composting process the rapid fermentation which is set up in the stack is continued during peak heating and probably just as much composting takes place then as in the stack.

To obtain rapid fermentation in a stack is not easy and requires some experience. The short-composting process is rather new to this country and those wishing to try it would be well advised to cut down the length of time in the stack gradually, at the same time ensuring that the compost is thoroughly wet and well aerated. There is general agreement that there is a saving in materials, and undoubtedly as more growers gain in experience the process will become even more widespread. It is also quite likely that the length of time in the stack could be reduced even more, so that eventually most of the composting will be done during the peak heating process, with much saving of labour.

So far, the M.R.A. type of synthetic compost has not been found very suitable for short composting procedures, but it must be remembered that at stacking very little decomposition has taken place whereas horse manure is decomposing to a greater or lesser extent from the time it is produced until the mushroom grower is ready to use it. Some of the synthetic composts used in the U.S.A are made within 10 days, with very satisfactory results.

OTHER MATERIALS

The wide variety of materials used in making compost for mushrooms has already been mentioned. The mushroom industry is a very live one, always

seeking improvements in methods and materials, so a short discussion of materials which are worth considering for compost making is given here.

Until recently pig manure has been condemned on the grounds that it ferments rapidly and becomes too hot. Rasmussen, in Denmark, has shown that pig manure can be used satisfactorily to make a mushroom compost, and at least one large farm in Britain uses pig manure extensively for mushroom composting. It is important to use it fresh, as it soon dries out and forms hard lumps if stored under cover, and it is then entirely unsuitable for the purpose. Pig manure needs less water during composting, but the finished product is very similar to compost made from horse manure except for its characteristic smell. As pig manure compost packs down, the bed area which can be filled is rather less than with horse manure composts, and this should be taken into account in estimating quantities required.

In some other countries, poultry manure has been used satisfactorily for composting with straw. In Britain it is used extensively at rates up to 2–3 cwt per ton to increase the nitrogen content of strawy horse manure and as an activator.

Sheep or cow manure has also been tried elsewhere for mushroom composting, but in Britain this manure rarely leaves the farm where it is produced, and even if it were found to be suitable for mushroom growing it would not be obtainable generally.

ACTIVATORS FOR SYNTHETIC COMPOSTS

At present the most satisfactory nitrogen source of M.R.A. synthetic compost is dried blood. The use of activated sludge and urea have already been discussed. A number of materials could be suggested to replace dried blood, which is expensive, but the M.R.A. formula was arrived at after extensive trials in which most of the commonly obtainable nitrogen fertilizers were tried. In these trials, hoof-and-horn also produced satisfactory crops but "Nitro-Chalk", sulphate of ammonia, and calcium cyanamide all proved much less suitable than dried blood.

CEREAL STRAWS

Wheat straw is one of the basic materials of mushroom growing whatever the type of compost used. It has become dearer over the years, and some new wheat varieties produce a hard, almost solid straw which is difficult to compost. Since varieties, such as Cappelle Desprez, Koga II and Bersee, are heavy yielders of grain and will probably remain popular, this type of straw is likely to dominate the market for some years to come. Experimental work on methods of composting hard straw is being carried out, and the answer may be to compost or peak heat for a longer period. While some difficulties have been experienced, growers appear to be successfully adapting their composting methods to suit hard straw manures.

STRAW SUBSTITUTES

Wheat straw is used almost exclusively in mushroom growing. Barley straw is much less satisfactory because of its softness and the tendency to make a

rather soggy product. Among other materials, bracken and bean straw have been used with some success to replace wheat straw. There are also available in some quantity each year other untried materials, such as mustard straw, pea straw, hop bines, oak husks, flax shires, and wood wastes, but adequate trials of new materials are expensive to undertake and need to be related to the possible saving in cost which might result from the use of the substitute. Unfortunately experience shows that once a suitable use for a waste material has been established, its price tends to increase in step with the demand.

MECHANIZATION

The preparation of a mushroom compost is arduous and makes great demands on labour, but the process lends itself to mechanization more than any other in mushroom growing, and the use of composting machines is widespread. The machines available range from small machines attached to small motor-driven implements to large self-propelled machines over 21 ft long and 10 ft high. Some of the machines are designed to break up the lumps and lift the loosened compost to a height of 6 ft or so to the top of the stack, others break up the compost and throw it a considerable distance where it can be shaped into a stack by wooden formers (see Plate I). A tractor with a fork-lift is also a useful piece of equipment for moving large quantities of manure and compost.

A most valuable piece of machinery for the user of synthetic compost is a straw cutter. This can perform a good job at stacking by cutting and bruising the straw so that it packs down well and decomposition takes place more readily.

In the production of the crop itself, automatic watering equipment has been developed, and there is a place for spraying and pumping equipment on most farms. It is probably true to say that the tray system lends itself most to mechanized growing, and machines for filling, spawning and casing are available. The use of roller conveyors and fork-lifts for moving the trays can also save much hard work (see Plate V).

Filling and Peak Heating

The process following composting is peak heating, which takes place either in a special heating room or in the growing house. The compost is filled into the trays or shelves and is then peak heated.

Before moving the compost into the peak heating or growing rooms it should be inspected and judged suitable (see page 15). Before filling, the compost should be turned to break up solid lumps, to aerate it and to allow even mixing of the heap. Excessively dry patches should be watered, but well-made compost should need little or no water. If the compost is not satisfactory when put into the houses the prospects of a good yield are very poor. After some experience it will be found that some shortcomings can be overcome during peak heating; but it is better to aim at producing a good compost rather than to rely on peak heating to put things right. A bad compost cannot be made into a good one just by peak heating.

Filling Shelves

The heat should be turned on in the house just before filling begins so as to prevent cooling of the compost. Filling the house should be completed in one day so that peak heating can begin at once. When this is not possible the heat is left on so that the compost already in the house does not cool down overnight.

The most usual way of conveying the compost into the house is to fill it into containers, such as wicker baskets, boxes, galvanized baths or sacks, in the turning shed, and transport these to the house on a hand-truck or trolley, or on mechanized runabouts (see Plate V).

The shelves are filled one at a time, usually beginning with the lower tiers, especially where movable bed-boards allow extra head room when filling the bottom and middle tiers. Experience will soon show how many containers are required for each section; evenness of packing is important for consistent cropping. The containers are tipped out into the shelves and the compost firmly packed in but *not* trodden because of the danger of making it too compact and of introducing disease on muddy boots. The compost should be patted into place by hand making sure that corners and edges are well filled; by doing this it is very little trouble to pack the centre of the beds evenly. A 9 in. depth of loosely packed compost can then be tamped down to 6 in. by using a flat piece of wood a little less in length than the width of the bed. Handles at each end enable two people to use the tool, one on either side of the shelf. At the end of the operation the compost should be evenly packed, with the surface as level as possible. Beds deeper than about 6 in. are probably best laid down in two layers, tamping down the bottom layer before adding a further batch of compost.

The compost should be fairly springy, tending to rise after being pressed down; the more springy the compost the firmer it should be tamped. Horse manure composts can usually be packed more densely than the very springy synthetic composts. When the manure is rather wet packing should not be too dense; on the other hand, if experience shows that the compost dries out readily during the period before casing or is rather dry at filling, denser packing is advisable.

When the beds have been filled, all loose compost from the floor should be carefully swept up. The ventilators should be closed and all cracks sealed with paper or plastic film, after which peak heating can begin.

Filling Trays

Rather more care is needed in filling trays because the proportion of corners and edges to total area is much greater than with shelves. Careless filling of shelves or trays can easily be detected by testing the packing in the corners and edges. They should be packed just as firmly as the centre. If this is not done, a considerable loss in effective cropping area results. Because of their uniform size it is relatively easy to ensure that each tray is filled with approximately the same amount of compost by always putting the same number of full buckets, or similar container, in each. If a filling machine is used for trays, care should be taken to see that it fills and packs them evenly.

The trays can be filled in or near the composting site and conveyed to the peak heating room or growing house on roller conveyors or trucks. There is less compost spilt with this system of growing.

For peak heating the trays are stacked close together with only 1–2 in. between the surface of the compost and the bottom of the tray above. This can be done by slats of wood or by having the ends of the trays 1–2 in. higher than the sides. The surface of the compost should be tamped level and should not touch the bottom of the tray above it. The rows of trays should not be more than two abreast; a better arrangement is to have single rows with about 6 in. between each row. The object of having a small amount of space between trays and rows is to allow free circulation of air during peak heating because closely stacked trays heat up unevenly.

As with the shelf system the heat should be turned on during filling and the compost given as little chance as possible of cooling.

Floor and Ridge Beds

Some growers who do not grow mushrooms all the year round make up flat beds on the floors of glasshouses for a winter crop. The construction of these is very similar to that of shelf beds. The site of the beds should be marked out by pegs and string before bringing in the compost. Unless the floor beds are given side supports the edges are sloped down to the ground at an angle of about 60 degrees and the finished bed should have a neat appearance. Packing and levelling are no less important than with shelf beds, and a level and evenly packed bed is much easier to case later on.

Instead of flat floor beds some growers make the beds in a series of ridges (see Plate VII). This requires skill and experience, but makes better use of the floor space available. For each ridge a base of about 2 ft is allowed, and at its highest point the ridge is about 18 in. high. A distance of about 1–1½ ft should be allowed between each ridge. The compost should be evenly packed, and the use of a wooden mould will make it easier to keep the ridge consistent in shape. To prevent excessive drying the ridges are sometimes covered with loose straw, but even so there is a risk of the top half of a ridge bed becoming too dry where artificial heat is employed.

Usually beds or ridges made on the floor are not peak heated, although there is no reason why the compost should not be peak heated beforehand. Some of the advantages of peak heating, particularly as a means of killing insect pests and controlling disease, may however be lost in moving the compost after peak heating.

Peak Heating

Peak heating consists in raising the temperature of the prepared compost to a temperature of about 130–140°F for a period of at least a day. Some growers peak heat for several days. There is no doubt that the peak-heating process results in better yields, but the exact reasons for this are not certain. Mushroom mycelium grows best in compost which has been produced at 130°F. In a stack such a temperature is not uniformly maintained, but the compost can be brought to a suitable condition if it is raised to a temperature of 130°F by peak heating for a period of up to a week before spawning. As a result of a successful peak heat all insect pests and nearly all fungal competitors and parasites are destroyed. The composting process is also continued and completed.

Just after being filled into the shelves or trays the compost may show a tendency to heat up of its own accord: usually, however, it is necessary to

supply extra heat to bring the temperature up to 130–140°F. Probably the best way to do this is by the injection of live steam into the air, with or without pipe heat. In this way a high humidity is maintained, and excessive drying of the compost reduced. Care has to be taken to raise the temperature gradually, otherwise condensation will occur on walls, ceiling and beds and the compost may be ruined. A very common method of supplementary heating, used particularly by shelf growers, is to set up coke braziers along the length of the centre gangway. This can be quite satisfactory provided the risk of fire is guarded against, but the surface of the compost can sometimes become very dry when this method is used. A cleaner method is the use of propane-butane gas burners, and suitable apparatus is now on the market.

It should be pointed out that unless buildings are specially designed considerable structural damage can be done to them by peak heating.

During peak heating, thermometers placed in the top, middle and bottom trays or shelves should be read at regular intervals. The top beds or trays are almost invariably the hottest. If the variation between top and bottom is so great that the bottom beds cannot be brought up to at least 120°F without the top beds exceeding 140°F some means of circulating the air within the house should be provided. To achieve a minimum of 130°F with no part of the compost exceeding 140°F, a system of air circulation is almost essential. Over-heating can result in disastrous crop losses; it is reported that on one occasion a temperature of 150°F for only a few hours resulted in complete crop failure. Should any part of the compost show a tendency to rise above 140°F the heat should be cut down and the ventilators should be opened for a while.

As the composting process during peak heating should be aerobic, ventilation is needed, but one change of air a day is probably sufficient. Ventilation should be gradual as it is important not to cool the beds too rapidly during peak heating.

Duration of Peak Heating

The duration of peak heating depends largely on the condition of the compost. A compost which has been in the stack for three or four weeks will probably need only a short peak heat of about 2–3 days at 130–140°F. Compost made by the short composting process may need longer, and some growers peak heat for up to seven days; this is phase 2 of the short composting process.

The time at which to finish peak heating is largely a matter of experience, but there are tests which may help the grower to decide. Some growers place great reliance on the pH test as a means of judging the state of the compost during peak heating. Readings are taken every day during the process, and when the pH has dropped to about 7–8 it is considered that the compost is ready for spawning and peak heating can be stopped. However, pH measurements on compost are not easy to make with accuracy or reliability, as very much depends on the conditions under which the measurement is made. One of the causes of high pH in compost is the presence of ammonia, and so long as ammonia can be detected by smell in a batch of compost it is not ready for spawning. One of the mushroom grower's most important tools is his nose, and after some experience a grower can learn much by smelling a compost.

Rasmussen has recently suggested a simple method for deciding whether peak heating is completed or not. Samples are taken from the beds at intervals of 6–12 hours, and as each sample is taken about 2 oz of compost are placed in a beaker or jar and ½ pint of distilled water poured over it. The beaker is left for ten minutes, and the excess water decanted into a clean test tube or similar container. The colour of the extract is noted. As subsequent samples are taken it is observed that the colour becomes lighter and lighter until a point is reached when no further change is observed between one sample and the next. At this point peak heating can be stopped. This method has not been tried extensively, but it is stated to be simple and effective.

Spawn and Spawning

It is vitally important that spawn should be entirely free from diseases, competitors and pests. This is achieved by specialist producers preparing it with very great care under completely hygienic conditions. The equipment required and the work involved in the process are considerable, and only in the case of very large establishments would there be any justification for setting up the necessary plant.*

The types of spawn available are manure spawn (moist), manure spawn (dry), manure spawn (granulated), and grain spawn. Moist manure spawn is probably used more than any other type. As the medium has not been dried out the mycelium is in an active state and, compared with dry manure spawn, should establish more quickly when introduced into the compost. Owing to the active condition of the mycelium it is undesirable to store this type of spawn for any length of time, but if this is unavoidable the cartons should be stored at a temperature between 35° and 45 F. The manufacturers arrange to despatch moist spawn as and when required, and this should mean that it is received on the holding on the day when the beds are ready for spawning.

Dry manure spawn is prepared by exactly the same methods except that it is dried after preparation. This renders the mycelium inactive, and the prepared cartons can be stored for several weeks without deteriorating. The activation of the spawn when introduced into a properly prepared compost is only a little slower than with moist spawn, and as it can be stored it is useful as a reserve to meet an emergency.

Granular manure spawn is a comparatively recent development and has been introduced to meet the requirements of growers who prefer to "sow" the spawn rather than "plant" it. It consists of dry spawn which has been broken down into very small pieces. As the individual portions are so small they are more likely to be affected by adverse conditions, such as too dry compost. It is claimed that the larger number of pieces of mycelium introduced should, under the best conditions, ensure that the compost is fully run

* For those who may be interested in the process, an account appeared in the Ministry's Journal, *Agriculture*, November 1946, Vol. 53, p. 353.

in the shortest possible time. It is also claimed that spawning can be carried out more quickly than by using the planting process in the orthodox manner.

Grain spawn is now widely used, especially by growers who use trays. The reasons for its popularity are the same as for granular spawn, namely, ease of application and quicker establishment. It probably suffers from the same disadvantage, however, that it is less tolerant than manure spawn of a compost which is not in first class condition. Grain spawn is prepared by introducing mycelium on to some form of cereal. Rye is a popular choice for this, and it is said that the suitability of varieties can differ appreciably. As with other types of spawn it is prepared under the most hygienic conditions by specialist manufacturers.

There are various strains or varieties of the cultivated mushroom. They range from white to brown, through various shades of cream. The white forms are grown to a much greater extent than any other colour as they are more acceptable to the buying public. To generalize, it may be said that the relative hardiness of the strains is connected with colour, white requiring more care and attention and a slightly higher temperature for optimum cropping than the brown varieties.

Spawn in its various forms is supplied in cartons or tinfoil-wrapped blocks. The care taken in its preparation calls for similar care when it arrives on the holding, to make sure that it is not exposed to contamination by pests or diseases.

Spawning

The spawn should be introduced into the compost when the temperature at three inches below the surface drops to 75°F. A higher temperature may damage the mycelium, but on the other hand growth will be very slow and the appearance of the crop delayed if the temperature is allowed to fall below 60°F before spawning. Since much harm may be done by spawning at incorrect temperatures a careful check, using thermometers inserted in the compost at various places in the house, should be carried out before a decision is made.

Cartons of manure spawn, either moist or dried, are broken into roughly equal portions, each about the size of a walnut. A quart-sized block can be divided into 30–40 portions. The density of planting varies, but spacing the portions at 9–10 in. each way is ample for a well-made compost. On this basis, the contents of one carton broken into 40 pieces will be sufficient for 23–26 sq. ft of bed. Wider spacing, however, is often practised, and a usual recommendation is that a quart carton is sufficient for 30–60 sq. ft of bed.

The pieces of spawn are planted so that the top of each is ½–1 in. below the surface. Care is necessary to ensure that the compost is pressed firmly around them as close contact is essential. Planting is often done with the fingers, but a stiff-bladed knife or a small mason's trowel can be used to make the openings. It is not advisable to use a dibber as it is more difficult to regulate the depth of planting and to ensure good contact between spawn and compost.

Grain and granulated spawn are usually scattered over the surface of the compost at the rate recommended by the makers and ruffled into the top inch of compost. A variation introduced recently is to mix the grain spawn throughout the whole of the compost. It is claimed that with this method the compost is fully occupied by mycelium more quickly.

Double spawning, i.e., the use of grain and manure spawn together, is another recent innovation which is claimed to give heavier crops. The grain spawn produces a quick and heavy first flush, after which the slower growing manure spawn takes over. There is thus a less rapid decline in the quantity of mushrooms produced than if the grain spawn alone had been used. It is important that the compost should not be too dry, otherwise the establishment of the mycelium may be delayed, if not prevented altogether.

The running of the mycelium should be observable after the spawn has been in position for about a week. This first takes the form of a faint greyish fringe growing out from the spawn, the fringe becoming whiter and more dense as it develops. With further growth it changes the dark brown colour of the compost to light brown, and this distinguishes it from the mycelium of moulds and most other fungi.

Casing Layer

The casing layer is the covering or casing that is spread over the compost surface to a depth of about 2 in. after it has been spawned. This layer is most important, for without it few, if any, mushrooms would be produced.

The exact function of the casing layer in bringing about fruiting is still uncertain, but work by Flegg at the Glasshouse Crops Research Institute has shown that the initiation of pinheads is directly related to the availability of moisture in the casing layer. When this is dry or contains excessive quantities of soluble salts, no fruiting occurs. As the availability of water increases the onset of fruiting becomes progressively earlier, and the number of mushrooms which develop is increased. Mushrooms do not normally form on uncased compost because of insufficient moisture and too high a concentration of soluble salts. When, however, the concentration of soluble salts at the surface of uncased compost is reduced by regular watering an appreciable number of mushrooms develop.

In commercial mushroom growing the conditions necessary to promote fruiting are most readily attained by using a casing layer which is kept moist by regular watering. The main purpose of watering is to maintain the conditions essential for the initiation of pinheads rather than to supply water for their subsequent development. Experimental evidence shows that in all probability the mushroom obtains most of its water from the compost, and not from the casing layer.

Undoubtedly other factors are involved in the initiation of fruiting, and mention may be made of growth substances, which are being studied by Kneebone and Schisler in the U.S.A.

Until about 1953 the traditional casing material in Great Britain was soil, but from that year onward the use of artificial mixtures containing peat became very popular, and by 1958 about nine-tenths of the growers in the country were using some sort of artificial mixture. It must not be imagined that the use of artificial casing mixtures confers any special freedom from diseases or pests; in fact, some troubles are even more likely with peat mixtures, and it is a wise precaution to steam-sterilize peat before use. It is

also not true that peat mixtures will give higher yields than can be obtained from a good soil. The chief advantage in the use of these mixtures is that a fairly standard material is used and can be altered at will. Many growers have no source of suitable casing soil nearby and would otherwise have to use an inferior soil or import it from outside at great expense. The labour-consuming job of soil digging is no longer necessary, however, since relatively little labour is needed to prepare the standard peat mixtures, and the basic materials for casing can be bought in bulk several months in advance and stored until required. In addition to soil and peat mixtures a wide variety of other materials can be used for casing. Limestone and gypsum rubble, brick chips, sandstone rubble, cloth and filter paper have all been used, although not necessarily on a commercial scale.

The main properties of a successful casing layer are:

(*a*) It should be capable of absorbing and holding a reasonable quantity of water and of withstanding repeated waterings without loss of structure.

(*b*) It should be sufficiently porous, even when wet, to allow carbon dioxide, and perhaps other gases, to escape from the compost, and oxygen to enter.

(*c*) It should be neither too acid nor too alkaline; the pH should be between 7 and 8.

(*d*) It should be free from pests and diseases.

A covering of peat, soil or similar material prevents the upper layers of the compost from drying out and gives some support to developing mushrooms. Although there is much to be learnt about the functions of the casing layer the introduction of peat mixtures has solved many problems for a large number of growers. There is now evidence, however, that the widespread use of these mixtures is giving rise to new disease, pest and cultural problems.

Peat Mixtures

Peat mixtures have been in use for a relatively short period and there is probably still much more to be learnt about the best types of mixture and their treatment. A very common mixture consists of either sphagnum or sedge peat mixed with an equal volume of lump chalk (usually $\frac{1}{4}$ in. to dust). Fibrous peat is preferred, although non-fibrous peats have proved satisfactory in the U.S.A. Sphagnum peat from Denmark, the Irish Republic or Germany is probably the most popular, but sedge peat dug in Britain has been found to be equally satisfactory. Many grades of peat are available, but not all are suitable for mushroom growing. When ordering, it should be specified that the peat is to be used for casing mushroom beds. It is not possible as yet to state that any one type or grade of peat is the best, for some growers find one kind most satisfactory, while others prefer another kind. Those wishing to try peat mixtures would be well advised to case a limited number of beds with each type of peat until they find the one best suited to their conditions. There is little doubt that the performance of a casing material depends to a great extent on the way it is treated and on the conditions in the growing houses.

Before making up the mixture the peat should be thoroughly wetted. Peat is not easy to wet and it is best wetted in bulk rather than trying to wet

it after it has been applied to the beds. Wetting can be carried out by breaking up the bale and soaking the peat in a large tank of water for some hours at least. The casing mixture is then mixed with a shovel rather in the same way as concrete is mixed; a concrete mixer has in fact been suggested as a suitable means for mixing large quantities of casing mixture. The final mix should be fairly well saturated, but there should be no run off of excess water. If this happens the mixture is too wet to apply and should be left until no further drainage takes place. If the mixture is applied when it is too wet, water will drain into the compost and cause damage to the compost and mycelium.

The pH of the final casing mixture should be between 7 and 8, and as some peats are very acid the pH should be adjusted before use. Normally this is not necessary if a 1:1 mixture of peat and lump chalk is used, especially if there is a proportion of dust in the lump chalk. If a lump chalk of $\frac{1}{4}$ $\frac{3}{8}$ in. is used, with no dust, then it is advisable to add some powdered calcium carbonate; about 20–28 lb per cwt of dry peat should be sufficient. Some growers add either calcium carbonate or hydrated lime in small quantities, whatever type of lump chalk is used, as an added precaution. There is no danger of having an excess of calcium carbonate, but if large quantities of hydrated lime are added there is a risk of the pH of the casing mixture becoming too high. In time, as the hydrated lime is converted to carbonate by the carbon dioxide of the air, the pH drops to a satisfactory level. It is therefore advisable, when hydrated lime is used, to allow the casing mixture to stand for a week or so before using it.

Other peat mixtures are used by some growers, including peat and sand in various proportions, or peat alone. In any case, sufficient calcium carbonate, 20–28 lb per cwt of dry peat, should be added to bring the pH up to 7–8. A few growers add coke breeze and similar materials to their peat-chalk mixtures. This is not essential, but it may help to reduce the total cost of the casing mixture over a given area. Some types of coke breeze and similar materials may, however, contain harmful substances, and this should be looked into before using them.

Soil

As the use of soil as a casing medium has declined sharply over the past few years only the main points need be mentioned. Some soils are more suitable than others, but there is no way of determining whether a soil is suitable except by an actual cropping trial. A medium clay subsoil which is fairly stable to watering is more likely to be satisfactory. It will hold water better than a sandy soil and will not pan or seal at the surface when watered continuously. Top soil can be used, but it should be sterilized before use either with steam or with formaldehyde. The pH of the soil should be tested and adjusted, if necessary, with calcium carbonate (ground chalk or ground limestone) to a value of 7–8. The quantities required are much less than with peat, usually up to 28 lb per ton will be sufficient if thoroughly mixed with the soil. It was suggested at one time that liming materials containing magnesium may be harmful, but this is unlikely.

The soil is best dug in the drier months as its structure can be damaged by handling when very wet. It is also easier to dig, sieve and break up to a satisfactory size when friable. There should not be an excess of fine dust, say less than 20 per cent, and the lumps should be about $\frac{3}{4}$ $\frac{1}{2}$ in. in diameter.

In selecting casing soil one should look for a fairly large area of soil showing as little variation in depth as possible. In some areas the nature of the soil varies considerably within a short depth, and difficulty will be encountered if there is a marked change in the type of soil used on the mushroom beds. Preferably, the top 1½–2 ft should be discarded, as disease organisms may be present. The subsoil should be sterile, and contamination with top soil should be avoided. All tools should be cleaned with dilute formalin before being brought into the casing soil pit, and workmen should dip the soles of their boots in a tray of disinfectant. If soil sterilization is necessary it is carried out in the normal way using steam or formaldehyde.*

Soil should not be used for casing when it is very wet for it is difficult to spread evenly, and a solid, impermeable layer of soil may result. It is best applied when slightly damp, otherwise much of the fine dust in extremely dry soil will run straight through into the compost.

Time of Casing

Although there is not much information on the optimum time for casing, it appears to be harmful to case before the growth of the spawn has reached a certain stage of development. However, there is no known way of judging when the spawn has reached the stage at which it should be cased, and growers have to discover for themselves, by trial and error, the best time for casing under their own conditions of growing. Whatever are the characteristics of a spawn run at the optimum time for casing, the time at which this is reached will obviously depend largely on the rate at which the mycelium grows. Most growers consider that the compost should be cased when the mycelium has completely colonized it. This is usually 10–21 days after spawning.

The Casing Operation

The object of the casing operation is to cover the compost with soil to an even depth of 1–1½ in., or to a slightly greater depth with a peat-chalk mixture. It is important that the casing layer should be as nearly uniform in depth over the compost as possible; this will make it easier to estimate water requirements. Great variations in depth of the casing layer lead to some areas being over-watered so that water runs through and soaks the top of the compost, while other areas do not receive sufficient water. Before applying the casing mixture the compost should be tamped to make sure the surface is level. Trays can be cased evenly by using a fixed volume of mixture or soil for each tray and smoothing the casing material evenly over the surface of the compost, paying special attention to the edges and corners.

The casing of shelf beds is begun at one end of the house, one shelf at a time, the casing mixture being tipped on to the surface of the compost and smoothed evenly over the surface a few square feet at a time. Some sort of gauge to check the evenness of depth of the casing layer is advisable. One method is to lay a wooden plank of the same thickness as the intended depth of the casing layer on the compost, and to make sure that the top surface of the casing material is level with the top surface of the plank. Tamping the

* See also Advisory Leaflet No. 319, "Soil Sterilization". Single copies obtainable free from the Ministry of Agriculture (Publications), Ruskin Avenue, Kew, Richmond, Surrey.

casing material as it is laid is permissible, but is should be sufficient only to ensure an even level surface; very little pressure should be necessary.

The casing of ridge beds is a skilled operation. Soil is usually used and it may be in a finer state of division than is desirable on shelves and trays. Starting at the bottom of the ridge a layer about 1½ in. thick and 1 ft high is applied and beaten lightly with the back of a spade to keep it in place. A further layer is laid in the same way, leaving the top and a small portion of each side until last. The soil should not be too dry otherwise it will fall away from the sides of the ridge.

Additions to Casing Layer

Growers have for long been interested in the possibility of increasing yields by the addition of some material or other to the casing layer, either at casing or during cropping. For many years common salt (sodium chloride) has been applied to the casing layer during cropping in the belief that the quality of the mushrooms is improved and that some freedom from disease is obtained. Experiments show that there are grounds for the belief, and further work is being carried out to discover the best quantity and kind of salt to use. The quantity used successfully by growers is usually 5 lb sodium chloride dissolved in 100 gal water and applied to the beds after casing or between the first and second flush. This type of treatment may eventually go a long way towards reducing the troublesome occurrence of crops of very small mushrooms.

There is also a possibility of increasing yields by adding finely divided compost to the casing layer at the rate of 2-6 oz dry compost per sq. ft. Fairly large scale trials have proved promising, and further trials are being carried out.

Crop Management

THERE are three phases in the management of mushroom beds or trays; spawn running, the period between casing and the appearance of the first mushrooms, and the cropping period. Each of these phases requires somewhat different treatment.

Air Temperature

During the spawn running period, a temperature of 70-75°F can be maintained in the houses or spawn running rooms. During this period the mushroom spawn should be growing vigorously, and within limits, the higher the temperature, the faster the growth rate. Higher temperatures than this, while permissible, are not recommended unless there is efficient thermostatic control, otherwise a slight further rise in temperature may kill the spawn.

After casing, the temperature should be reduced to about 65°F, and when the first pinheads appear it should be again reduced to about 60°F for the rest of the cropping period. Cropping at about 65°F is practised by some growers; this results in quicker cropping and allows a shorter cropping period, but increases the danger of outbreaks of disease.

TWO TYPES OF COMPOSTING MACHINES

PLATE I

HOUSE OF CORRUGATED ASBESTOS ON 3 FT WALL, WITH EXTERNAL INSULATION

HOUSE OF CORRUGATED ASBESTOS ON A CONCRETE BASE, WITH INTERNAL INSULATION

GLASSHOUSES CONVERTED FOR MUSHROOM GROWING BY COVERING WITH FIBRE-GLASS, ROOFING-FELT AND WIRE-NETTING

AN INEXPENSIVE HOME-MADE STRUCTURE OF BREEZE BLOCKS AND CORRUGATED IRON

PLATE III

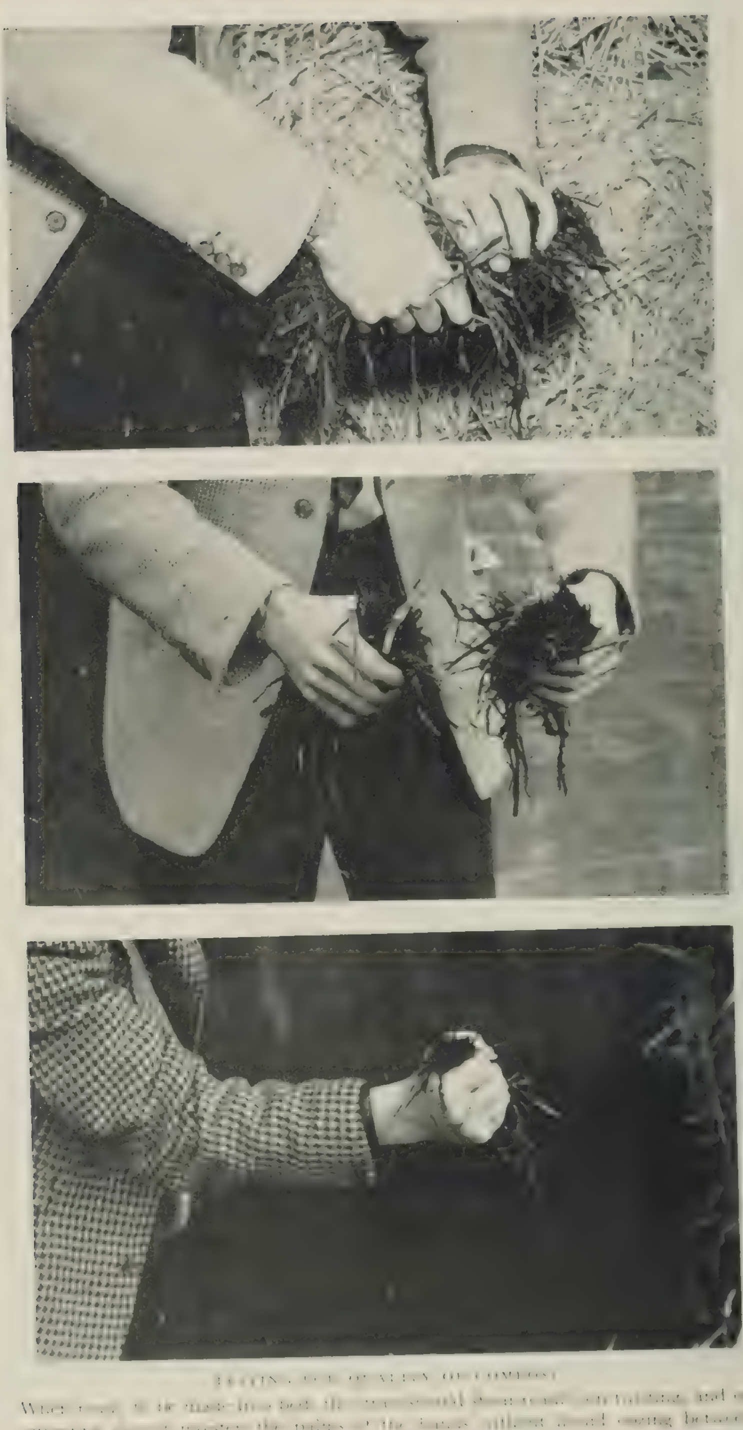

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PLATE IV

TRAYS ON A MANUALLY-OPERATED LIFT TRUCK

TRAYS ON A MECHANICALLY-OPERATED TRUCK

PLATE V

SHELF BEDS

Note polythene ventilating tubes between shelves on left

CHEQUERBOARD ARRANGEMENT OF TRAYS

Note roof supports

PLATE VI

TRAYS IN MULTIPLE UNITS FORMING SHELVES

RIDGE BEDS

PLATE VII

PICKING A CUP

TRIMMING

REMOVING THE STUMP

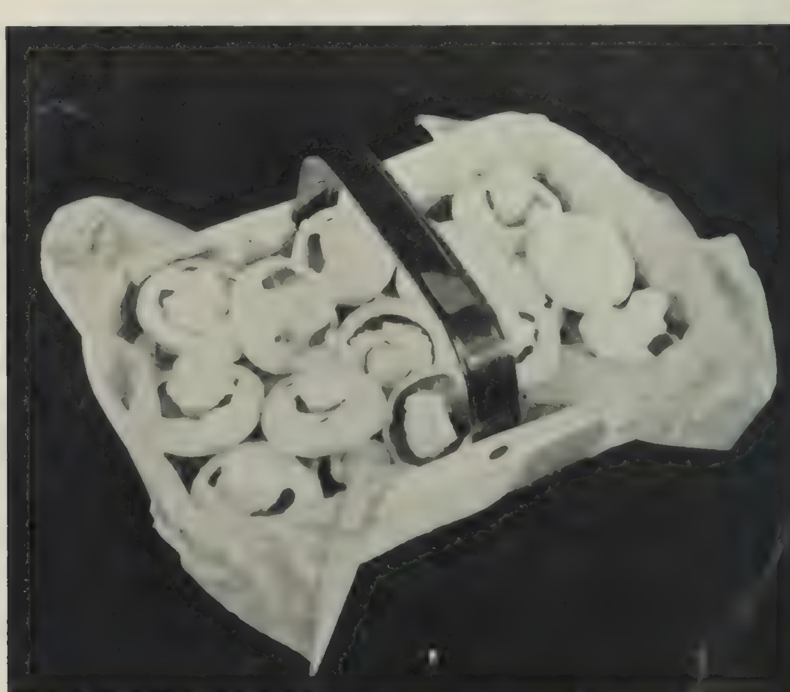
FILLING THE HOLE

PLATE IX

GRADES

Top: Selected Buttons—"R" Grade

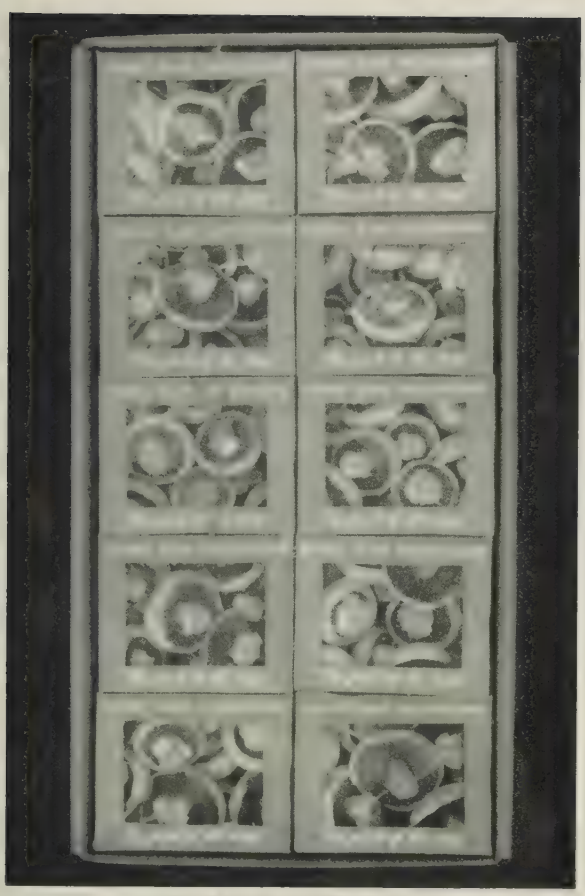
Bottom Left: Selected Cups—"R" Grade *Bottom Right:* Selected Opens—"R" Grade



PACKING

Mushrooms [illegible]

PLATE X

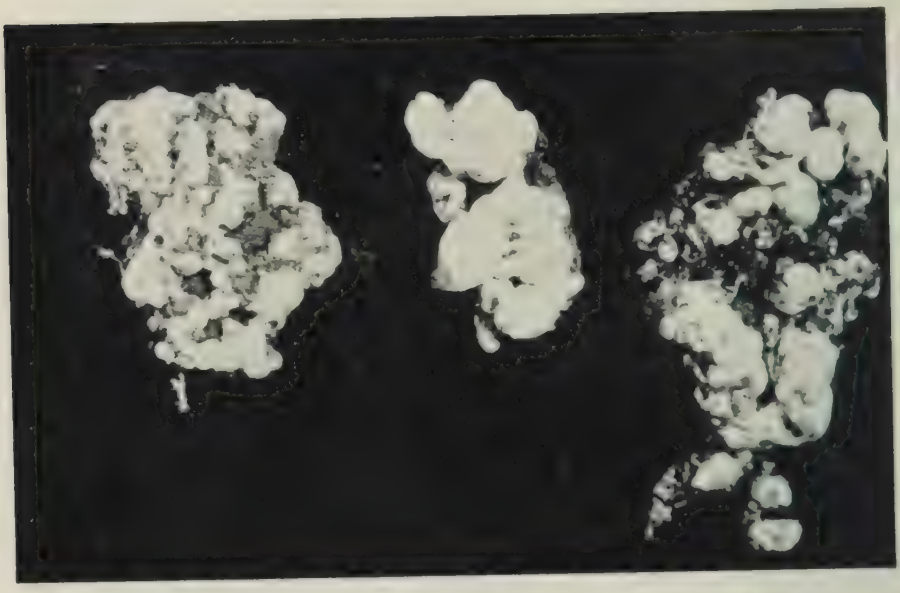


PRE-PACKED MUSHROOMS

WATERING
A fine rose should be used

PLATE XI

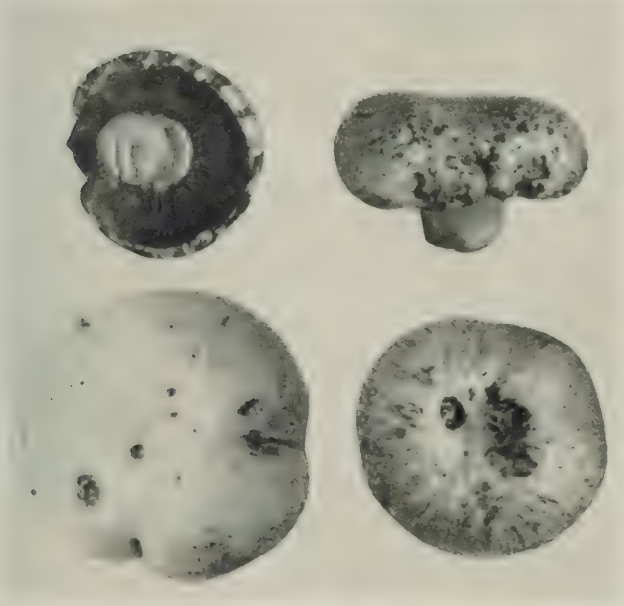
MUSHROOMS ATTACKED AND DEFORMED BY WHITE MOULD (*Mycogyne ferruginosa*) DISEASE



FRUITING BODIES OF TRUFFLE (*Pondichalongia mirifica*) FROM CASING SOIL OF MUSHROOM BED

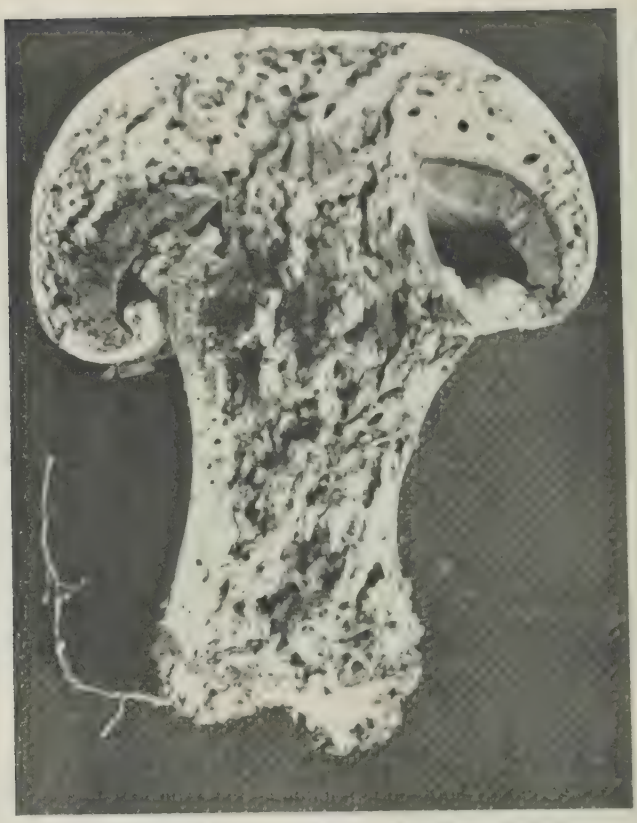
PLATE XII

DEFORMITY FOLLOWING INFECTION BY *Verticillium malthousei*
Downward peeling of stalk is typical



BACTERIAL PIT

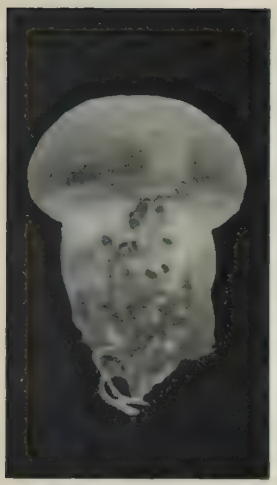
PLATE XIII



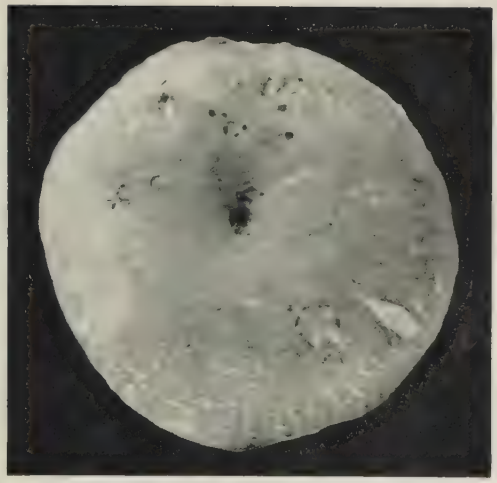
TUNNELLING CAUSED BY LARVAE OF PHORID FLY

DAMAGE CAUSED BY THROGLYSHID (*left*) AND [illegible] (*right*)

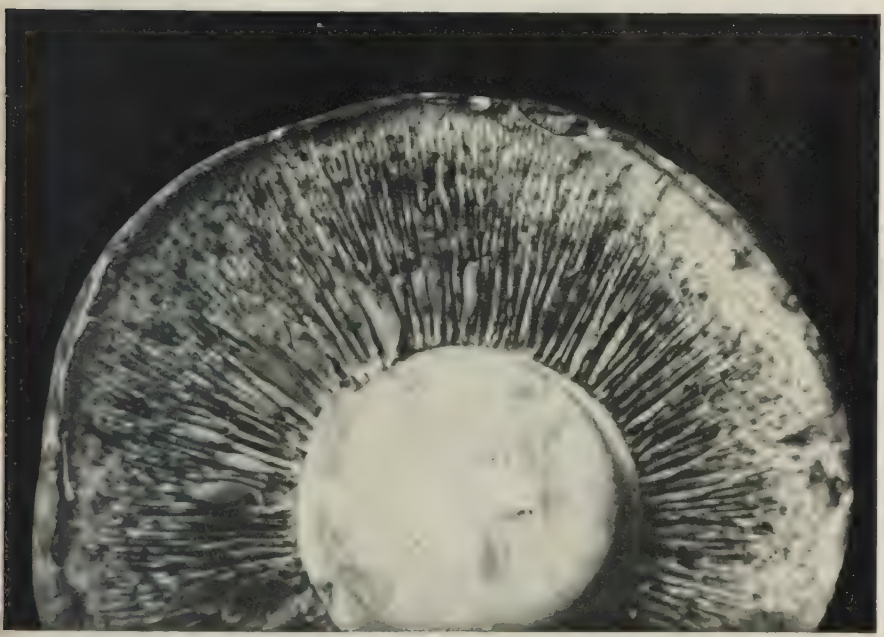
PLATE XIV



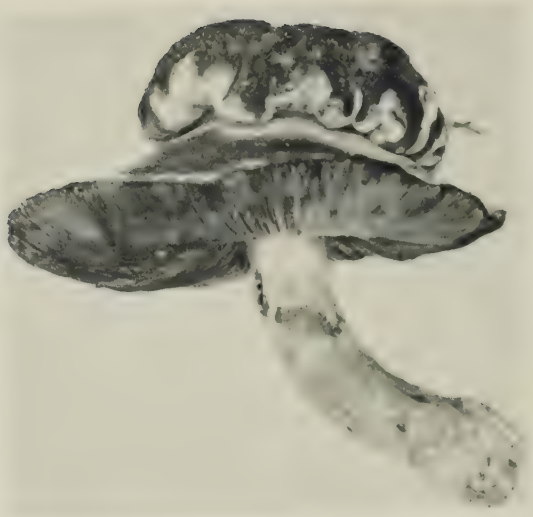
HOLES IN STALK CAUSED BY SPRINGTAILS [$\times 1\frac{1}{2}$]



MATURE MUSHROOM SHOWING HOLES IN CAP ALSO CAUSED BY SPRINGTAILS [*Nat. size*]



DAMAGE CAUSED BY CECIDS



ROSE COMB
Deformity of mushroom due to mineral oil

HOUSE HYGIENE
Protective clothing for formaldehyde spraying

Atmospheric Humidity

Mushrooms develop best in an atmosphere with a high relative humidity. In caves and quarries the relative humidity is naturally very high, often 90 per cent or more, but in buildings it is not usually possible to maintain such a condition for more than short periods. However, the relative humidity in mushroom houses should be kept above 70 per cent. This can be achieved by spraying walls and floors with water and, if possible, by releasing small quantities of live steam into the houses. High relative humidity should not be achieved at the expense of adequate ventilation.

Ventilation

Little ventilation is required during spawn running and it should be sufficient to change the air once or twice a day. Ventilation should be increased after casing, otherwise pinheads may not form. The greatest amount of ventilation is required during the cropping period, and about 2–4 complete air changes per hour have been recommended. It has been shown that a concentration of 1 per cent carbon dioxide in the atmosphere can result in the production of deformed mushrooms. Ventilation during cropping has a two-fold effect: it removes gaseous waste products and allows the mushrooms to dry off after watering. Evidence has been obtained which indicates that the movement of air over the beds has an important physiological function. Cropping has been improved when air has been recirculated inside a house without any increase in the rate of air renewal.

Ventilation can be achieved by the installation of ventilators at ground and roof level (see Plate II). This is usually satisfactory except when conditions inside the house are about the same as those outside, as can happen in the summer when the heating is off. When this happens, ventilation depends largely on the direction and force of the wind, and at times there may be insufficient air movement to give adequate ventilation. The problem of air circulation can be overcome by fans, but they are not entirely satisfactory as under the conditions mentioned the humidity of the incoming air is relatively unchanged; consequently in humid weather the air coming into the house may retard the evaporation of water from the beds. There is some evidence to show that this can cause or aggravate certain types of mushroom disorder.

Recirculation of air within the house can be obtained by fans fitted to a system of ducts, or by placing a mobile fan inside the house and changing its position periodically. Good control of ventilation and air conditions should be obtainable with an air conditioning system, but this is expensive to install and, at the moment, information on the optimum environmental conditions for cropping is lacking. However, a number of growers have installed forms of air conditioning with fans, ducting and a means of heating and humidifying incoming air, some with beneficial results. Draughts must be avoided as they cause cracking and discoloration of the mushroom caps.

Watering

If the compost begins to dry out seriously during the spawn run it can be lightly sprinkled with water. This should not be done too frequently, as it may retard the growth of the mycelium. It is more desirable to reduce water loss from the compost by maintaining a moist atmosphere, which should be easily accomplished at this stage since not much ventilation is required.

Although the casing layer is put on in a fairly wet condition, it soon begins to dry out and watering becomes necessary. Drying out can again be retarded by maintaining a moist atmosphere, but ventilation should be increased at this stage. If this is not done and the air has a high relative humidity, a thick layer of mushroom tissue may form on the surface of the casing. This is called a stroma and the grower may have difficulty in inducing the mushroom to fruit normally.

Watering should be carried out with a fine rose or mist spray. The casing must be kept moist throughout its depth, but it must not be allowed to become waterlogged. The amount of water applied should be sufficient to keep the casing moist without wetting the compost below. If the top of the compost becomes too wet in the early stages of the crop, the mycelium may have difficulty in penetrating the casing (see Plate XI).

The frequency of watering depends on the atmospheric conditions in the house. It may vary from once a day to once a week, but the average is about three times a week. If daily watering is necessary, it shows that ventilation is excessive or the atmosphere is much too dry, and attempts should be made to remedy this by reducing ventilation, watering floors and sealing cracks in walls or elsewhere. The more frequently it is necessary to water the greater the danger of damaging the mycelium in the compost. Watering may have to be increased during cropping, but there is less danger of damaging the mycelium when it has completely colonized the compost since excess water usually drains through, but even then over-watering should be avoided. Watering is best carried out after picking, but should it be necessary to water when mushrooms are on the beds, care should be taken to see that there is adequate ventilation to dry them out afterwards, otherwise they may be attacked by bacteria. If necessary the temperature should be raised slightly. Under drying conditions mushrooms may be damaged when water falls on the cap, a brown stain being formed.

Routine Management of Beds and Trays

The beds and trays should be regularly inspected and "ink caps" (*Coprinus* spp.) or other weed fungi removed. In districts where mushroom flies are troublesome the houses should be regularly sprayed or dusted with a suitable insecticide from the time of spawning. If this operation is delayed until flies are seen in the house, the infestation may well be already beyond control. If any diseased mushrooms appear, they should be immediately removed and burnt and the area where they appeared treated with formaldehyde. This will probably kill the mushroom mycelium as well as the disease organism, but it is better to sacrifice a few mushrooms than to let the disease spread unchecked. Diseased material should *never* be removed by pickers during picking, for this is the surest way of spreading a disease throughout the farm.

Trashing, i.e., the removal of dead mushrooms and stumps, is usually carried out on shelves but not always on trays. The original reason for this was that trays are usually cropped for a maximum period of six weeks and with the tight schedule of operations it was not economical to trash them. With shelves the cropping period is longer and stumps or dead mushrooms are more likely to become a source of infection. Shelves, by their very nature, do not offer the same barrier to the spread of infection as trays. However,

the newer strains of spawn appear to crop more rapidly and for a shorter period than the older types, so that the cycle of cropping has been speeded up, with the result that trashing is no longer carried out by some shelf growers. After trashing, the holes left in the surface of the beds should be filled with fresh casing material.

Cropping Period and Yield

The time taken to produce a crop of mushrooms depends on a large number of factors, such as temperature, quality of compost and casing, type of spawn and the skill of the grower. For this reason times given here can only be approximate. With a temperature of about 65°F the time between casing and the appearance of the first pinheads is about two to three weeks, but this period varies according to the time allowed for spawn running. With the tray system, the usual cropping period is six weeks. At the end of this time the trays are emptied, although they are by no means exhausted, as the object of the system is to keep the trays in a state of maximum production at all times.

The cropping period on shelves is somewhat longer, but here, too, there has been a tendency in recent years to reduce the cropping period. This has been brought about by the use of spawns developed originally for the tray system. Such spawns produce most of the crop in the first two or three flushes and thereafter production falls off rapidly. Shelves are now cropped for eight to ten weeks, seldom longer.

The yield also depends on a large number of different factors which cannot be discussed here in detail. One of the most important is the system of growing adopted. On trays an average yield is $1\frac{1}{4}$–$1\frac{1}{2}$ lb per sq. ft, while on shelves it is 2–$2\frac{1}{2}$ lb per sq. ft. It should be remembered, however, that a larger number of crops can be obtained in a year on trays than on shelves, and that the yearly yield from the two systems may be much the same.

Beds and trays are not normally kept in crop until they become exhausted, as it is most uneconomical to do so. Although the compost may no longer produce mushrooms, possibly because of the accumulation of staling products, the compost is still a useful manure for many other crops. Attempts have been made to prolong the life of the crop by watering the beds with various chemicals, but this has not been successful.

Disposal of Used Compost

Although used compost is a valuable manure for a number of horticultural crops, the mushroom grower should take care in disposing of it, so that is does not become a potential source of trouble. If is is not wanted for other crops, it should be immediately removed from the farm. If it is used on the holding, it should be kept as far away from the cropping houses as possible and ploughed in without delay. Used compost may contain disease organisms, the spores of which are easily blown back into the cropping houses. It also contains mycelium which attracts mushroom flies, and for this reason it may become a breeding ground for these pests. Cooking out before emptying lessens the risk but does not eliminate it entirely. Used compost should never be dumped near ground from which casing soil may possibly be dug.

Picking, Grading and Packing

PICKING

Mushrooms normally develop through stages known as buttons and cups to open mushrooms or flats (see Plate X). Buttons and cups realize the best prices although there is a demand for opens. To get the maximum returns, therefore, care is necessary to ensure that mushrooms are picked as soon as ready. Development proceeds rapidly when once the cup has expanded sufficiently towards the breaking point of the membrane, and with beds in full bearing it is essential to pick over once a day. At other times picking on alternate days may be sufficient.

Mushrooms should be twisted gently from the beds (Plate VIII) and not cut or pulled. Some of the casing layer is commonly brought away with the root-like mycelial threads at the base of the mushrooms, and any of the solid basal part of the gathered mushroom accidentally left in the casing should be removed (Plate IX), otherwise it provides a medium in which flies may deposit eggs. Where cropping is to be continued over a long period, holes made in the casing layer during picking should be filled as soon as possible with fresh soil or casing mixture, suitably sterilized. When a short crop is taken, this work is not justified. Damaged mushrooms and broken pieces must be picked up and not left lying about.

Although it is not an invariable practice, it is preferable to trim mushrooms as they are picked because there is a danger of loose particles from the bed or casing soiling them, if they are placed in trays or baskets before trimming. It is not necessary to make the final trim at this stage; an economical outlet can frequently be found for clean stalks, hence only the dirty stumps should be removed, and these should be placed in a waste bin at once (see Plate IX). The trimmed mushrooms are placed stalks upwards into trays or baskets for conveyance to the packing shed where grading and final preparation for the market takes place. A few growers, however, grade and pack in the mushroom house.

GRADING AND PACKING

Grading and packing should be done under cool, airy conditions to maintain the quality and retard the development of the mushrooms. The first operation is to make the final trimming. The stalks should have a maximum length of $\frac{3}{4}$–1 in., according to the size and grade of the cap, unless the mushrooms are to be packed into consumer units, when the length of the stalk should be $\frac{1}{4}$ in. The mushrooms are then sorted into grades according to quality and stage of development. First (or Selected) quality mushrooms of between 1-in. and $2\frac{1}{2}$-in. diameter are divided into: *buttons*, mushrooms in which the membrane is firmly intact, and likely to remain unbroken for twenty-four hours; *cups*, where the membrane is breaking and the caps retain a pronounced downward curve; and *flats*, where the gills are fully or nearly fully visible and the cap forms a letter T with the stalk.

Mushrooms under 1 in. or over 2½ in. in diameter should be marketed separately to suit local preference, and mushrooms that are broken or otherwise damaged, dirty, or seriously discoloured should be marketed separately, undescribed, or described as "seconds".

"Recommended" grades have been adopted by the Ministry of Agriculture on the advice of the Advisory Committee on Standard Grades and Packs and in agreement with the Mushroom Growers' Association. Full details of the "Recommended" grades for cultivated mushrooms are given in the Ministry's Marketing Guide No. 14.* (See also Plate X).

Since mushrooms lose weight rapidly, they should be packed overweight to ensure that the full reputed weight is likely to be received by the retailer. The amount of overweight required is a matter of judgment, depending on the time elapsing, and the temperatures to be expected between packing and sale to the retailer. To assist in achieving full weight it is recommended that mushrooms should be placed in the container in orderly layers, stalks upward. This also enhances the appearance of the pack, and facilitates inspection. If a mushroom is packed stalk downwards, the spores fall out as the gills open and soil the mushrooms packed underneath (see Plate X).

Covers, adequately secured to the package, should be clearly marked with the type of mushroom (white, cream or brown), the grade, and the grower's name or mark. This enables a buyer, with his knowledge of the reliability of the sender, to bid accordingly and the produce to pass rapidly through the processes of sale, realizing the best price.

Mushrooms should be marketed in chip baskets of the size found most suitable for the particular market concerned. The preference today is for a maximum of 4 lb in any container, and the most popular weights are 2 lb and 2½ lb, but the following containers may be used:

No. 2 Chip Basket	No. 6 Taper Chip Basket
No. 4 Chip Basket	No. 7 Taper Chip Basket

Mushrooms have a high unit value, are very subject to handling damage, and as such lend themselves to packaging into consumer units. This has now become a popular method of presenting the button and cup grades to the public. Opens are not considered suitable for this type of trade. The packages preferred are overwrapped cartons or trays holding ¼ lb. Permeable film should be used for overwrapping because conditions of high humidity within the carton should be avoided as they lead to excessive stalk elongation at temperatures around 65°F. Single layer non-returnable trays of wood or cardboard make satisfactory master containers in which to market these consumer unit packages (see Plate XI).

If they have to be retained in a fresh state, mushrooms can be kept for some days under cool conditions at temperatures between 34° and 45°F, but they must not be frozen.

* Obtainable free from the Ministry of Agriculture (Publications), Ruskin Avenue, Kew, Richmond, Surrey.

Diseases and Competitors

Complete or partial failure of the mushroom crop may be the result of faults in cultural methods, environmental conditions, disease, competition with other fungi, or attack by pests.

Diseases are caused by infection of the mushroom with other fungi or with bacteria. The existence of virus diseases has not so far been demonstrated. The most common of the disease-causing fungi are *Mycogone perniciosa* (white mould or bubbles), *Verticillium malthousei* and *V. psalliotae* (dry bubble or Verticillium disease), and *Dactylium dendroides* (*Hypomyces rosellus*) (cobweb disease). Among the bacterial diseases, *Pseudomonas tolaasi* causes baterial blotch or spot.

The most serious competitors are *Diehliomyces microsporus* (*Pseudobalsamia microspora*) (truffle) and various types of yellow mould.

A large number of other fungi are frequently found in the casing and compost, and many of them may also have an adverse effect on mushroom production. Properly made compost favours the growth of the mushroom mycelium to the exclusion of most other fungi. If compost is found to have a large and varied fungus flora, then either the composting method, or the subsequent treatment of the compost, has probably been at fault.

There are a number of serious mushroom disorders of which the cause is still unknown. Among these are mummy disease and La France disease. Unfortunately such disorders have greatly increased in recent years. Some of them may be partly or entirely caused by environmental conditions. Inadequate ventilation, for instance, will cause distortions of various kinds, often with a lengthening of the stipes and a reduction in the diameter of the caps. Draughts, on the other hand, may cause discoloration, stunting and cracking of the caps. Mushrooms with underdeveloped gills and veils have been known for many years, but the cause is still not known.

Damage to mushrooms is sometimes chemical in origin. Fumes of mineral oils, creosote of unsuitable grades, and the improper use of some phenolic disinfectants may cause a deformity, known as rose comb, in which tumours are produced on the caps (see Plate XVI).

In dealing with mushroom diseases, prevention is always better than cure for several reasons. Firstly, control of the fungal diseases of mushrooms is difficult because it is a problem of one fungus parasitic on another one. Consequently, many fungicides which would kill the parasites easily cannot be used because they would also kill the mushrooms. Selective fungicides have been developed in recent years, but they are few in number and do not always give effective control of disease. Mushrooms are a short-lived crop and if a disease outbreak occurs there is little time in which to bring it under control. Consequently, a disease outbreak which only lasts for a week or two may result in the loss of much of the crop. Many established growers prefer to throw out a crop which had become diseased rather than leave it in the house where it would remain a potential danger to crops in other houses.

It is advisable, when possible, to heat up beds or trays to 160 F before emptying, especially if disease has been present. This can be accompanied by

fumigation with formaldehyde, or the fumigation can be delayed until the house is empty. Houses, bed-boards or trays should always be thoroughly disinfected after emptying (see also Crop and House Hygiene, on p. 60).

FUNGAL DISEASES

White Mould or Bubbles

White mould (*Mycogone perniciosa*) may attack mushroom in any stage of growth. If a mushroom is lightly attacked in a late stage of development, *Mycogone* is generally found growing on the gills. The gills are often wavy in appearance and are covered with a close, white, velvety growth. A mushroom attacked more severely will be considerably distorted and may merely consist of a globular mass of tissue completely covered with the white mould. Mushrooms attacked by *Mycogone* exude drops of a golden liquid, and they rapidly decay with the emission of a foul odour. Another species, *M. rosea*, has been recorded as attacking mushrooms, causing a browning of the cap, but is not of economic importance (see Plate XII).

Control. High temperatures at cropping time favour infection by this mould, the optimum being 75°F. At lower temperatures the rate of spread is slower. It is most commonly introduced in casing soil. Once it appears in a mushroom house it produces myriads of spores which can be carried to all parts of the house on air currents, tools or workers' hands. When it has appeared on a farm there is a danger that it will infect successive crops unless strict measures of hygiene are adopted. Infected mushrooms and a surrounding 6 in. margin of the bed should be sprayed with 5 per cent commercial formaldehyde to kill the fungus. After spraying, the diseased mushrooms should be removed and burnt before picking and watering. Pickers should never remove diseased material, as their hands will become contaminated and they will spread the disease throughout the house.

The disease can also be controlled by the use of zineb, either as a dust (4 oz per 1,000 sq. ft of bed, applied weekly) or spray (1 lb per 100 gal water, using 1 gal on 50–100 sq. ft of bed, applied before fruiting or between flushes). Another promising treatment is the use of chlorinated water containing 100 p.p.m. of available chlorine, the chlorine being added as sodium hypochlorite solution. Neither of these treatments will control a heavy infection once it has been allowed to establish itself. If *Mycogone* appears regularly these treatments should be applied as part of routine management, to avoid a build-up of the disease.

If soil for casing is suspected of being contaminated, it should be disinfected before use, either by steaming or by treatment with formaldehyde.

Dry Bubble or Verticillium Disease

The first symptom of infection, due to *Verticillium malthousei* or *V. psalliotae*, is the production of light brown, irregularly shaped blotches and spots on the caps of mushrooms. If these discoloured areas are examined under a hand lens, a fine grey-white mould may be seen growing on the surface of the mushroom cap. In more severe attacks the mushrooms become distorted. The caps may be irregular in shape, and the stalks split and peel in a characteristic manner. In severe cases the stalks are swollen and bulbous, the cap very small or absent, and the mould covers the surface of the mushroom.

The growth is less close and white than that of *Mycogone*, and not so profuse. Affected mushrooms become dry and leathery and do not produce an offensive odour (see Plate XIII).

Control. The treatment is similar to that recommended for *Mycogone*. Chlorinated water has given much more decisive control of *Verticillium* than of *Mycogone*. This fungus produces enormous numbers of very small spores. These are easily disseminated by air currents, and unless checked early on the disease will spread rapidly through the house, disfiguring a large proportion of the mushrooms. The spores can lodge in innumerable cracks in woodwork, etc., and for this reason a house in which *Verticillium* has appeared should be very thoroughly disinfected after emptying; otherwise there is serious risk of the disease being carried over into the next crop. Casing soil suspected of *Verticillium* infection should be disinfected, either chemically or with steam, before use.

Cobweb Disease

On beds infected with cobweb disease (*Dactylium dendroides*) (*Hypomyces rosellus*) a rapidly growing downy or fluffy mould creeps over the surface covering single mushrooms or whole clumps with a cobweb-like mycelium. The colour is white, often with a rosy tint. Mushrooms, when covered by the fungus, completely rot away. Spores are disseminated by air currents, by watering, and by human and insect agencies.

Control. The treatment is similar to that recommended for *Mycogone* and *Verticillium*. Zineb will control the disease, but chlorinated water has given inconclusive results. Promising results, however, have obtained with quintozene (PCNB). Bed-boards and woodwork should be sprayed with a solution containing 1 lb of 75 per cent wettable powder in 100 gal water. The beds or trays can be sprayed with a 100 p.p.m. solution immediately after casing, or 500–1,000 p.p.m. solution after the first flush has been picked.

Gill Mildew

Gill mildew (*Cephalosporium lamellicola*) appears to be similar to a disease recorded as due to the fungus *Acremonium*. It produces, in its initial stages, symptoms identical with those caused by a mild attack of *Verticillium*, namely brown blotches on the mushroom caps. Later, a fine cobweb-like mycellium may be found growing over the gills, the lamellae of which may be stuck together. It appears to be of minor importance only. Treatment is the same as for *Verticillium* disease.

Trichoderma viride

Trichoderma viride is a dark green mould, commonly found in soil, which occasionally attack mushrooms, causing blotching of caps and sometimes peeling of stalks. It is encouraged by damp conditions, and may be harboured in old stumps left in the beds. This disease also is of minor importance.

BACTERIAL DISEASES

Bacterial Blotch or Spot

In bacterial blotch or spot disease, usually caused by *Pseudomonas tolaasi*, although the symptoms can also be produced by *Bacillus polymyxa*, there is

surface blotching of the caps, the blotches being yellow at first, then turning brown. They may become so extensive that the whole surface of the caps becomes brown and sticky. The source from which the bacteria come is unknown, but the disease is favoured by conditions of high humidity and a low rate of ventilation.

Control. After watering, sufficient ventilation should be given to allow the mushrooms to dry off fairly quickly. Regular watering of beds with chlorinated water containing 100–200 p.p.m. of available chlorine can reduce considerably the number of blemished mushrooms produced.

Bacterial Pit

The exact nature of bacterial pit is not known, but bacteria are normally associated with it. *Bacillus polymyxa* can cause symptoms of the disease, but *Pseudomonas fluorescens* is sometimes associated with them. Small pits or cavities appear just below the surface of the caps, the covering skin eventually collapsing and leaving an open pit in which bacteria are invariably found (see Plate XIII). There is evidence to indicate that the disease is soilborne in the first instance, but it may also be air-borne. Chlorinated water (100 p.p.m.) has reduced the incidence of this disease.

DISORDERS OF UNKNOWN CAUSE

Mummy Disease

Mummy disease has been described in detail by Tucker and Routein (1942) in the U.S.A. It has since been identified in the United Kingdom. It has some similarity to damping-off caused by *Fusarium* spp., but no causal organism has been isolated. Affected mushrooms develop long slender stalks and small tilted caps. They turn brown and die, remaining on the beds in a dry, mummified condition. The stalks have a gritty texture when cut across with a sharp knife.

The disease can be transmitted through infected compost or casing, but not through affected mushrooms. It spreads at the rate of about 1 ft per day, and infection is likely to be present 4–6 ft in advance of the youngest visible diseased mushrooms. Its progress may be checked by digging narrow trenches across the bed, 6–8 ft in advance of the visibly affected margin. The disease does not readily spread from bed to bed. The infective principle can be inactivated by heating, drying, or the application of disinfectants such as formaldehyde.

La France Disease

Some of the symptoms of La France disease are similar to those produced by mummy disease, but according to Sinden who first described it, it is quite distinct. The disease may appear at the beginning of the cropping period, or later on. Affected mushrooms are produced singly rather than in clumps; they have long stalks and small globular caps and die in a soft, wet rot. No further mushrooms are produced in the affected areas. The disease is stated by Sinden to be infectious and can only be eliminated by strict attention to hygiene, especially when cleaning out houses in which the disease has appeared. There is evidence to indicate that the disease is airborne.

La France disease is believed to have been the cause of serious crop losses in this country in 1956 and 1957. Positive identification is difficult as the

cause is not known. The symptoms are in some respects similar to both mummy and *Fusarium*, and some of them could also be due to unfavourable environmental conditions.

Brown Disease and Watery Stipe

During 1957 mushroom crops in many parts of Britain were affected by disorders to which various names were given by growers, the two most popular being brown disease and watery stipe. These names referred to two of the commonest symptoms, namely a discoloration of the affected mushrooms and the development of transluscent streaks in the stalks (stipes) caused by waterlogging of the tissues. Reduction of crop was considerable and serious. Other symptoms associated with the outbreaks were: elongated stalks, death of immature mushrooms, reduced rizomorph development at the base of the stalk, vestigial gills and veils — an abnormality that has been known for many years. Nearly all these symptoms have been described as typical of one or other mushroom disease, e.g., translucent streaks are a symptom of mummy disease, and the death of immature mushrooms is one of the symptoms of damping-off (see page 43).

It is generally agreed that this trouble is not new but has only recently become of economic importance. Some of the 1957 outbreaks were identified by Sinden as La France disease, although the symptoms observed differed in some respects from those given in his published description of the disease. The situation with regard to these outbreaks remains confused at present. The variety of symptoms observed and the differences in the behaviour of individual outbreaks suggests that more than one disorder of this type may exist.

As to the possible causes of these outbreaks, they tend to be more common during periods of high humidity and temperature, when ventilation inside mushroom houses is not always satisfactory. This suggests that unsatisfactory environmental conditions may be responsible. On the other hand, a disorder has been transmitted by inoculating newly spawned beds with compost from affected crops, thus suggesting the presence of an infectious agent. Until more reliable information is available, all outbreaks of disorders of this nature should be treated as infectious and the houses cooked out after cropping. Disinfection of houses, woodwork, etc., with DNC sodium salt is recommended.

COMPETITORS

Truffle

The fungus *Dichliomyces microsporus* (*Pseudobalsamia microspora*) is not the edible truffle, but is related to it. After the compost and casing have been filled with mushroom mycelium, the spores germinate and a cream coloured mycelium overruns the already occupied bed. The fruiting bodies are typically sub-spherical in shape, ½ 1 in. in diameter, with a convoluted surface; their appearance has been likened to calves' brains. They may be produced in great abundance in the compost or casing layer (see Plate XII).

Each fruiting body contains large numbers of spores which are released when the outer covering decays. The spores themselves may then be distributed in the house or elsewhere on the premises and so contaminate future crops. The spores require a temperature of about 60 F or more in

order to germinate, and little or no growth appears to take place until the alkalinity of the compost is reduced by the running of the mushroom spawn in it. Spores of this fungus are extremely difficult to kill with normal fungicides or with heat. They have survived a temperature of 180°F for five hours.

Truffle is probably introduced initially in casing soil. After an attack develops and the fruiting bodies decay, the compost and woodwork from infected beds or trays remain a source of infection.

Control. If truffle is discovered in small patches in an early stage of development, saturation of the sites with formaldehyde may kill the fungus before spore formation occurs. If it is not discovered until fruit body formation is taking place, and is restricted to one or two patches, its spread can be prevented by cutting trenches across the beds as in the treatment for mummy disease.

If truffle appears regularly, it can in some circumstances be prevented from developing by treating the compost with copper sulphate, 1½ lb dissolved in 10 gal water per ton of manure; this should be sprayed on to the compost just prior to filling. Copper sulphate should not be put into galvanized containers.

Damping-off

Damping-off due to *Fusarium oxysporum* and *F. martii* results from the toxic effect of *Fusarium* on mushroom mycelium in the bed. There may be little or no mushroom production, or, after a good first flush, the crop may degenerate into small, withered, brown and under-developed buttons which remain on the beds without rotting. In a normal or healthy crop some of the mushrooms are found to be dry and pithy inside the stalk; they are of pith-like texture and usually brown internally. Sometimes the trouble is localized in patches or is confined to one or more beds in a house.

Control. There is no known control. Once *Fusarium* has appeared in a house, the woodwork may become contaminated and the disease may pass to successive crops unless rigorous steps are taken to eliminate it. Creosote has been found efficacious in killing it and some of the newer disinfectants are probably equally effective. Species of *Fusarium* normally inhabit soil and can be eliminated by steaming.

White Plaster Mould

The common name is derived from the appearance of the mould *Scopulariopsis fimicola* on the bed as scattered plaster or lime. There is good evidence that white plaster mould is usually brought into the house with compost, and copious development of mycelium occurs after the beds have been made up. If casing is not carried out fairly soon, white patches of the sporulating fungus appear on the surface, but more often the patches are not seen until the fungus has passed through the casing soil and appeared as a patch of "plaster" on the surface.

This fungus is favoured by alkaline conditions and, unlike truffle, does damage by occupying the compost before the mushroom mycelium has spread. It used to cause substantial losses to mushroom growers before the addition of gypsum to composts was general. Since then it has been of minor importance.

Brown Plaster Mould

Brown plaster mould (due to *Papulaspora byssina*) is first seen as fluffy or matted white patches on the surface of compost or casing. Soon afterwards the centre of each patch turns brown with the formation of a powdery mass of bulbils which give a granular appearance. As each colony matures it becomes completely brown. Mushrooms often break through the patches of brown plaster mould, but they appear later than in unaffected areas, and the yield is reduced.

The disease is probably introduced into the compost, and its development appears to be favoured by unsuitable composting which results in the production of soggy, "green" compost. It is generally of minor importance and should be easily controlled by proper composting and attention to hygiene on the composting site.

Red Geotrichum

Red geotrichum is the growers' name for a velvety, white fungus (*Sporendonema purpurascens*) which appears in small colonies mainly on or near the surface of the casing. As spore production begins, the mycelium turns first a buff colour, and finally pink. Severe outbreaks can reduce crop yields considerably. Quintozene (PCNB) used as a spray or as a dust has proved to be highly effective against this disease.

Yellow Moulds

A yellow fungus (*Myceliophthora lutea*) which attacks spawn was described many years ago and given the common name "vert-de-gris". More recently a form of vert-de-gris (mat disease) occurred in the U.S.A., in which the fungus developed in a layer between the compost and casing. There is now considerable evidence to indicate that neither of the two fungi found in the so-called mat disease were *M. lutea*, which in fact is rarely found in mushroom compost.

Since the name vert-de-gris should only be applied to *M. lutea*, the general term "yellow moulds" has been introduced to denote the yellow fungi found in mushroom beds. Three of these fungi are commonly found, but so far they have not been identified and named.

One of these moulds (Yellow Mould 1) is seen, when manure spawn is used, first growing round the pieces of spawn, i.e., in the region of the oldest mushroom mycelium. It produces a very fine white mycelium which disappears when the spores mature. Large numbers of lemon yellow spores are produced, and the fungus has a characteristic pungent odour, somewhat like chlorine, which may be very noticeable at emptying time. The mould forms between the compost and the casing, but in severe infestations it penetrates the whole of the compost. At times quite a satisfactory crop of mushrooms may be produced, even with severe infestation, while at others cropping is reduced.

Another of these moulds (Yellow Mould 2) produces similar mycelium and spores but it develops well defined globular colonies, ¼–2 in. in diameter, often coalescing to form large irregularly shaped patches and turning buff as the spores mature. These colonies may be scattered throughout the compost or may form a mat between compost and casing. It may cause serious crop losses.

The third mould (Yellow Mould 3) also has a white mycelium, but it forms small, fluffy, greenish-yellow colonies, and appears to be of only minor importance.

Control. The true status of these yellow moulds has not been established, and information is rather conflicting. Some of them may be truly parasitic, others competitors only. Owing to the enormous numbers of spores produced there is a risk of spreading these moulds when affected houses are emptied Precautions should be taken to minimize this by keeping doors and ventilators of all other houses closed whilst emptying is in progress. No effective chemical treatment has been found.

Olive Green Mould

The appearance of the fungus olive green mould (*Chaetomium* sp.) is generally regarded as a sign of over peak heating. High temperatures favour its development, and areas in which it develops are not readily colonized by mushroom mycelium. The fruiting bodies are olive green and about the size of a pin's head. With proper management, this fungus should not be troublesome.

Insect and Other Pests

Numerous insects and other small creatures live at the expense of fungi, and although cultivated mushrooms have their share, comparatively few are of great importance where the crop is grown in modern mushroom houses. Most growers suffer losses from them from time to time, and many find it necessary to adopt control measures against some as a routine.

The compost is one of the most important potential sources of pests. The major pests are flies, mites, springtails and eelworms, many of which live naturally in stable manure and compost, and feed largely on fungi. Some pests are attracted by the growing crop and may enter through ventilators and other openings. Casing soil, when it is subsoil, is unlikely to be an important carrier of pests, except perhaps eelworms, some of which may also be introduced with peat used as casing.

Slugs, millepedes and woodlice are minor pests, and are fairly general feeders that sometimes include fungi in their diet. They normally have little chance of colonizing a mushroom house, and usually only occur where mushrooms are grown in outdoor beds, or in adapted buildings not well sealed from adjoining soil or other shelter which can harbour them.

Many insects and mites may be seen in and about the manure heap or in the beds themselves. They sometimes cause alarm, though many are quite harmless species living on decaying organic matter or preying on or parasitizing other insects and mites. For example, borborid flies, which are harmless and often abundant inhabitants of the manure heap, have been mistaken for pest species of phorid flies. Although some pest species may be recognized by their characteristic damage, identification is best left to a specialist.

In the following sections the various pests are described and specific control measures suggested, but it need not be assumed that all these measures must be continually put into effect. This is particularly true of premises

where strict sanitation and efficient peak heating are practised (see Crop and House Hygiene on page 60). Serious trouble from most pests generally occurs spasmodically, and not often from more than one at a time. Frequently, too, attacks by a pest may be repeated in a run of crops and then cease as mysteriously as they began (see Routine Use of Insecticides on page 59).

FLIES

Over a dozen species of flies have so far been identified as pests and most of them are of major importance. They belong to three families: sciarid flies, phorid flies and cecid midges. Other flies occasionally seen in the mushroom house include the small dark borborid flies already mentioned. Although one of these has been bred from mushrooms already damaged by other flies, they seem to be by preference inhabitants of the manure heap and not pests. Fruit flies sometimes occur, but they seem only to breed in mushrooms that have begun to decay. Much larger flies, resembling the house fly, may also be seen on the windows, but these are the adults of larvae which have bred in the manure and are in no way harmful.

Sciarid Flies

Before the advent of BHC and DDT sciarid flies were among the most serious of mushroom pests, being of almost constant occurrence, and continued vigilance is still necessary to prevent them causing damage. Nearly a dozen different species have been reared from mushrooms and compost, but the significance of many of them to mushroom growing is still not understood.

Lycoriella fenestralis appears to be a common injurious species. It is a small, delicate, two-winged insect, about one-twelfth of an inch in length with black head and thorax, dark brown abdomen, and antennae nearly as long as the body. Although winged it does not fly freely but runs rapidly over the mushroom bed, making short jumping flights. Its blunt oval eggs, translucent white in colour, are laid singly or, more usually, in strings of four to nine on the casing soil or the bases of the stalks, and they hatch in four to seven days. The larvae are white legless maggots, with a shining black head, and are about one-fifth of an inch in length when fully grown. They tunnel into the mushroom where they feed for fifteen to twenty days, then descend to the casing where they build a cocoon and enter the pupa or chrysalis stage. This lasts for eight to fourteen days and the adults usually pair on the day of emergence, the female beginning to lay eggs two or three days later. She can lay at least thirty eggs.

Both stalk and cap may be tunnelled, and in severe cases the whole mushroom is reduced to a sponge-like mass. As few as three to five larvae can cause sufficient damage to spoil the market value of a mushroom. They may also sever the mycelium from the stalk and cause the buttons to die and turn brown. If they are sufficiently numerous when the spawn is beginning to run, they may restrict its growth. Sciarid infestations may develop at any time of the year, and with a life cycle which can be completed in about a month, serious trouble can arise if the insects are not kept in check.

Sciarids can occur in the manure heap, and larvae have been found in parts of a heap where the temperature was as high as 162 F, but successive turns were found to eliminate them. Little is known about the temperatures lethal to them, but observations and experience suggest that, especially

where the outer parts of the heap are moved to the inside at turning, the heat of fermentation is sufficient to destroy most of them. The flies could of course lay eggs in the cooler outer layers after the last turn, but any infestation arising in this way would again be subject to high temperatures during peak heating.

The adults are attracted by the growing crop and are liable to enter through ventilators and other openings. In addition to the direct damage they can bring about, they can also carry with them the spores of *Verticillium* and the migratory stages of some tyroglyphid mites and probably of eelworms (*Rhabditis*).

Control. There seems little doubt that the common practice of raising compost and air temperatures to at least 120° and often to 130–140°F for many hours at peak heating leads to the production of a compost free of sciarid larvae, and that any infestations arising during cropping are due to flies entering the building and laying eggs after spawning. Routine fumigation with *gamma*-BHC smoke at peak heating is frequently adopted, and although the value of such a measure may be open to question where high temperatures are achieved, it is probably a useful adjunct, especially where temperatures do not reach about 120 F, as sometimes happens in the lower shelves and in floor beds.

Dusting the beds after spawning with a *gamma*-BHC dust at about ½–1 lb per 1,000 sq. ft of bed, followed by further dusting just before and another after casing, appear to give excellent protection, and dusting can be repeated if necessary during cropping, provided that it is done after picking hard.

Some growers adopt similar measures as a routine, others find it sufficient to dust when the presence of flies requires attention. If the beds are exceptionally exposed to the risk of serious attacks it is important to remember that eggs may be laid as soon as there is any growth of mycelium, so that insecticide should be applied immediately after spawning. *Gamma*-BHC smokes, or aerosols of *gamma*-BHC, malathion or diazinon, probably leave lighter and less persistent deposits, but they are useful, especially with tray growing when the boxes are tightly stacked in the peak heating room. During spawn running, more or less weekly treatments are given.

Where for some reason an attack develops during cropping, the beds can be sprayed with *gamma*-BHC at ordinary strength (see page 57), and this measure should enable insecticide to be washed into the casing to reach larvae feeding on the mycelium, though no attempt should of course be made to wet the compost itself. Where *gamma*-BHC is mixed with the compost for the control of cecids, it is likely to control sciarids as well, and might obviate the need for surface dusting or fumigation. Care in hygiene is always important; stumps, and old mushrooms may attract flies and should be removed. Screening of ventilators is recommended (see page 61).

Phorid Flies

Until 1953 the only phorid well known as a mushroom pest in Britain was *Megaselia nigra*. Twenty years ago this not infrequently caused trouble, especially in the summer months and in outdoor beds. Serious attacks are now rare, possibly due to the routine use of insecticides. The larvae tunnel in mushrooms causing damage similar to that by sciarids, but little is known about its habits and life-history (see Plate XIV).

In 1953 two more phorid pests were recognized. *M. bovista* was recorded from a crop in Shropshire, the larvae tunnelling in the mushrooms and almost completely destroying the crop. The other, *M. halterata*, became known as the "Worthing phorid" and in that year was responsible for one of the most remarkable of insect pest epidemics. The reason for this is not understood, but attacks increased in severity from May or June onwards until by late summer the insect was present in countless thousands in most mushroom-growing nurseries of the Worthing area of West Sussex, and in scattered nurseries in East Sussex, Kent, Lancashire and Norfolk. Heavy infestations persisted well into the winter and caused very serious losses. They occurred again in 1954 when they affected many nurseries which were free in 1953. Subsequently this phorid seems to have become established as one of the major mushroom pests, although it has disappeared from many nurseries as mysteriously as it came. Since 1953, winters have frequently been mild and infestations have followed a regular pattern, falling to low levels after cold, hard weather in January and February, then increasing again during the summer to high levels in late summer and autumn and continuing well into the new year.

In Holland, where *M. halterata* has been known as a mushroom pest for some years, it is stated that the larvae tunnel in mushrooms, but in Britain the larvae confine themselves to the mycelium in the beds. The flies have not been found in the manure heap, but are attracted by mushroom mycelium and will lay eggs in pieces of spawn as soon as these are planted in the beds. At this stage, the larvae cause serious checks to the growth of mycelium and even complete crop failures, but when occurring later, after the compost is well run, they are less harmful unless infestations are very heavy. Experiments with crops in small trays show that phorid populations may increase to 1,000 larvae and pupae per sq. ft of bed 6 in. deep without marked crop reduction. Populations of 10,000 or so have commonly occurred, and have been associated with loose and crumbling casing owing to the cutting up of the mycelium.

Phorid flies are small, dark insects with shorter wings than those of sciarids, and with a stouter body of a slightly humped appearance. The antennae are bristle-like and inconspicuous. Their larvae are white and legless, but in contrast with sciarid maggots they lack the black head case and are rather thicker in the body. Under laboratory conditions *M. halterata* completes a life cycle on mushroom spawn in 3–4 weeks in summer and 6–8 weeks in winter. The female lays 50–60 long ovoid, creamy white eggs, which hatch in 3–7 days. The larvae feed for one or two weeks and the rest of the time is occupied by a relatively long pupal period. At the Glasshouse Crops Research Institute it has been found that under certain conditions with temperatures of 70–75 F the pupal period may apparently be reduced to a few days, and the life cycle completed in about nine days. When newly emerged the flies are pale and cannot fly until their wings are fully extended and hardened. Both sexes are attracted to light, except presumably the female when she is ready to lay a batch of eggs. It is possible that females may mate and lay eggs before flying out of the mushroom bed. Parasitism of all stages except the egg by an eelworm, *Bradynema*, has recently been recorded at the Glasshouse Crops Research Institute, where it was found that as much as four-fifths of a population of flies was affected, the females being able to lay few or no eggs.

Control. Measures normally used with success against sciarids have proved inadequate against the phorid *M. halterata*, since even exceptionally frequent and heavy dustings with 5 per cent BHC or DDT dusts, or smokes or aerosols of these insecticides, have failed to control it. Growers' experiences suggest that the flies rapidly developed resistance to insecticides such as *gamma*-BHC and DDT, and experimental work supports this view.

The insecticides which have proved most useful are malathion and diazinon, principally in aerosol form directed against the adult flies. It is most important to provide protection in the critical period when the spawn is running. During this time aerosols should be used once or twice weekly and increased to almost daily applications if flies become abundant in late summer and autumn. Treatments can be less frequent during cropping, the number being judged according to the abundance of flies. On a small scale malathion or diazinon dusts can be blown into the house at 3–4 oz per 1,000 cu. ft as a substitute for aerosol treatment (see page 58 for precautions in use).

While the spawn is running and ventilation is not so important as during cropping the houses should be kept closed, and all ventilators screened to keep out adult flies (see page 61). Mixing 5 per cent malathion dust with the compost at not more than 2–3 lb per ton can give good control, but this rate should not be exceeded or it may reduce cropping. The method is troublesome in practice, since it is advisable to wear a light respirator if there is any risk of breathing quantities of dust.

Cecid Midges

The adult midges are very small and delicate two-winged flies, rarely seen by the mushroom grower. The larvae are slender, with a small inconspicuous head, and are white, yellowish white or orange in colour. They may be distinguished from other mushroom fly maggots by the presence of a dark brown spot (ocular spot) in the body just behind the head; sometimes there is a dark brown structure on the underside of the forebody known as the "breast bone" or "anchor process", but this only develops in the larvae that give rise to pupae (pupa-larvae). Larvae can give birth direct to daughter larvae, and this process can go on for months or even years without the intervention of a pupal stage or the production of adult midges. Enormous populations of larvae can develop in this way.

Four species of cecid have so far been recorded from mushrooms in Britain. *Lestremia cinerea* is a common cecid but appears only occasionally to attack mushrooms. *Mycophila speyeri* and *M. barnesi* have been recorded a number of times, and the orange larvae are occasionally met with, though as a rule only in small numbers. By far the commonest is *Heteropeza pygmaea* which was first recognized in 1949 from midges reared from mushrooms in Kent, though it was probably the midge responsible for an infestation recorded in 1928. The larvae are white, and the anchor process in the pupa-larva stage is spear-shaped in contrast with the trident-shaped one in *Mycophila*. The pupa-larvae are about $\frac{1}{8}$ in. long, but the daughter larvae, which are the ones most commonly seen, are only half as long.

Under dry conditions *Heteropeza* larvae tend to remain in the compost, but watering often brings large numbers to the surface, when they may accumulate on the side boards and many fall on the ground. On a dry floor they can be seen jumping spasmodically, eventually becoming tangled together in masses. This gregarious habit may furnish some protection

against drying up and has been noted in sciarid as well as in cecid larvae. The reason for the effect of watering is not known, unless it is that the excess of moisture merely aids the movement of overcrowded larvae. This would partly explain why the use of peat as a casing material, capable of holding more water than soil, seems to have been followed by more noticeable cecid infestations. The female midge appears to lay only a few eggs, and from these hatch larvae which give rise to daughter larvae. These feed on the body contents of the mother larva, from which they eventually escape, leaving behind nothing but an empty dead skin. This process can go on indefinitely and under favourable conditions each larva may produce about 15 daughter larvae in 8–9 days.

Under some conditions a special larva is produced which gives birth to 3–5 "pupa larvae". In 4–5 days these develop the anchor process and the ocular spot becomes separated into two. These larvae eventually form the chrysalis or pupal stage, from which the adult midges emerge in about 5 days. What conditions bring about this production of adults is not yet clear, though there is a suggestion that slow starvation of a culture causes most of the larvae to become pupa-larvae. It is unusual to find large numbers of adults in a mushroom house.

Heteropeza larvae are seen in moderate numbers from time to time by some growers, with no evident or marked reduction in cropping, especially in the relatively short cropping period with tray growing. Sometimes, however, the larvae ascend the mushrooms in sufficient numbers to cause trouble, by burying themselves in the surface tissues and giving a discoloured streaky appearance to cap and stem. The gills may be damaged and look as though they have been nibbled, but this has also been seen in the absence of cecids, and often accompanied by milky exudations. The cecid larvae sometimes destroy some of the mycelial attachments at the base of the stalk, and mushrooms so attacked tend to turn brown. The mycelium may also be damaged, and it may disappear from large areas of the beds when infestations are heavy. Damage to the mushrooms and mycelium by the other species mentioned is likely to be similar, but little information is available (see Plate XV).

It is not known with certainty how midge infestations arise in the first place. *Heteropeza* larvae have been found in decaying wood and in a peaty soil, and *Mycophila barnesi* in garden manure, rotting potatoes and unused casing peat, so that the midges may well find suitable breeding places in the neighbourhood of the mushroom farm. The manure heap may become infested through midges laying eggs in it or by larvae persisting on the composting site, and midges may lay eggs in the beds after spawning. It is also known that after an attack larvae can persist in crevices in the woodwork so that crop after crop becomes infested. As the adult midges are so small, it is doubtful if simple screening of ventilators could be used to prevent their entry, because the very fine mesh needed would seriously impede air movement.

Control. It is necessary to guard against the occurrence of larvae in the compost, the carry-over of larvae in woodwork from a previous crop, and infestation of beds in the cropping house by midges entering and laying eggs.

On some farms efficient peak heating gets rid of most larvae from the beds at the outset, and no further measures may be necessary. Larvae of *M. barnesi* are killed at a temperature of 99 F, and those of *Heteropeza* at

113°F, so that a peak-heat of about 130°F for some 4–8 hours should destroy larvae in the compost and in the crevices in boxes. This treatment is carried out most successfully by tray growers, where there are no permanent wooden structures in the cropping house, and the trays of compost can be pasteurized in a peak heating chamber fed with steam circulated by fans to ensure even distribution of heat. Some shelf growers achieve similar results by introducing steam into the house at peak heat, using fans to ensure that all parts of the house reach a high enough temperature.

Sometimes in spite of these precautions cecid infestations occur, and the best preventive appears to be mixing *gamma*-BHC with the compost. This is particularly useful where it is difficult to achieve sufficiently high peak heat temperatures, and where there is a risk of carry-over of larvae in woodwork which it is sometimes almost impossible to disinfest by chemical means alone. Work at the Glasshouse Crops Research Institute has shown that mixing about 50 p.p.m. (by weight) *gamma*-BHC with the compost prevents the development of cecid populations. This quantity could be given, for example, by about $\frac{4}{5}$ fl. oz of a 10 per cent miscible concentrate per 100 lb of compost. It should be applied in a little water, about $\frac{1}{3}$ pint, with the spray gun and sprayed as evenly as possible over the compost. A convenient time to do this is when the boxes are being filled for peak-heating, and care can be taken to see that spray and compost are well mixed. Where the compost can safely take more water, the same quantity of insecticide could be given in a larger quantity of water, which can be applied with a watering can and rose.

Dusts are less easy to mix thoroughly with compost, but as *gamma*-BHC is very persistent the insecticide could probably be applied with the gypsum, using about 20 lb of 0·45 per cent *gamma*-BHC per ton of manure. The subsequent turns should help to achieve a fairly even mixing, though this method of application has not been tried experimentally. Where for any reason a cecid attack has been allowed to develop, it can be checked by spraying or dusting with diazinon.

MITES

Mites are very common but owing to their small size usually do not attract attention until they are present in large numbers. They are often numerous in the manure heap and sometimes in the beds themselves, but are mostly quite harmless species. Predatory mites are frequently seen; these feed upon mites and other small animals, and they may usually be distinguished from pest species by their rapid movements and by the shining yellowish brown colour of the adults. The species of importance to the mushroom grower are the tyroglyphids, the long-legged mite (*Linopodes*), the tarsonemid and related mites. The mite population of the manure heap generally dwindles as composting proceeds and many must be killed by the heat of fermentation, though some probably escape to the cooler outer layers after each turn.

Tyroglyphid Mites

Tyroglyphid mites have soft, translucent, whitish bodies, often clothed with long fine hairs, and are sluggish in their movements. They are not as a rule plentiful in stable manure, and in recent years they have become uncommon as pests. They may possibly become more numerous in manure

which is left undisturbed and partially dried out, and this might account for the serious infestations which used to be associated with the use of old accumulations of stable manure.

Little is known about the habits and distribution of the species attacking mushrooms, and there are still doubts about their identity. The commoner mushroom mites appear to be similar or closely related to *Tyrophagus longior* and *T. putrescentiae*, which are sometimes common on straw and grain. Other closely related mites similar in appearance and recorded as damaging mushrooms are *Caloglyphus krameri* and *Eberhardia*.

Tyrophagus excavate small irregular cavities in the stalk and cap of mushrooms, the cavities being moist and stained with excreta in contrast with the dry pits and tunnels made by springtails (see page 53). The cavities should not be confused with those occurring in bacterial pit, which begins as a point of breakdown just beneath the surface, the covering skin ultimately collapsing and leaving an open pit (see Plate XIV). Sometimes mites which would not attack a healthy mushroom find their way into these pits and might be suspected as the cause of the damage. Tyroglyphid mites also feed on mycelium, and have been known to destroy grain spawn before there could be any run of mycelium.

Although tyroglyphid mites are probably most often introduced with the compost, some species could be brought in by insects carrying on their bodies a migratory stage known as a hypopus. This is a special stage frequently produced during the mite's development, possibly when colonies become overcrowded; it has suckers which enable it to cling to passing insects, and on reaching a suitable environment it can transform to an adult ready to breed. Since the mites can complete their life cycle in about three weeks under mushroom house conditions, an infestation can soon be brought about in this way.

Long-legged Mushroom Mite

The long-legged mushroom mite (*Linopodes antennaepes*, and a closely related species of *Ereynetes* have several times been recorded as pests, though they seem only to occur in situations where the mites have access to the beds from surrounding soil or other shelter. They are small whitish mites with long legs, waving the fore pair like a pair of antennae as they move about, and in *Linopedes* the forelegs are more than three times the length of the body. Both run rapidly and hide in the compost when disturbed. Damage associated with them is severance of the "roots" so that affected mushrooms tend to topple over, and the bases of the stems are found to have a reddish brown discoloration (see Plate XIV).

Tarsonemid and Related Mites

Most growers are familiar with the minute yellowish brown mites which sometimes occur in great numbers, swarming on high points in the casing and on the caps of the mushrooms giving an appearance that has earned them the name of red pepper mites. Few identifications of these mites have been made in Britain, but *Pygmephorus tarsalis* is common. This is parthenogenetic and reproduces itself rapidly, though there is no evidence of damage to the crop and it is mainly a nuisance in causing irritation to workers. *P. americanus*, which in the U.S.A. is said to retard the growth of mycelium, has been recorded in Britain. In the U.S.A. a *Tarsonemus* species has caused

serious losses by eating tiny pits in the surface of the stems and caps, but in Britain only one case is recorded. This was in Kent in 1956, when on one nursery a *Tarsonemus* species swarmed in large numbers at the base of the stalk of occasional mushrooms in the beds. Surface feeding caused a brown discoloration at the base, and the mycelial attachments were severed as in damage by *Linopodes* (see page 52). Some of the attacked mushrooms were entirely brown.

Control. The use of fresh manure, together with efficient composting and peak heating, are probably the best means of preventing trouble from mites, at any rate the tyroglyphids. It is always important that organic debris in the buildings, especially in glasshouses, should be cleared away or destroyed. The red pepper mites appear to be more difficult to control, and it is hard to understand how infestations persist in spite of peak heat of the order of 140°F for eight hours. In the U.S.A. severe outbreaks have occurred after peak heat temperatures exceeding 150°F, although mites are killed by temperatures around 130°F.

Tyroglyphid mites, the long-legged mite and *Ereynetes* are susceptible to *gamma*-BHC, and this insecticide can be used where composting and peak heating conditions are indifferent. A *gamma*-BHC dust at $\frac{1}{2}$–1 lb per 1,000 sq. ft of bed area, as suggested for the control of sciarid flies, i.e., after spawning and before and after casing, and again during cropping as required, should be adequate. Sprays of *gamma*-BHC at normal strength may also be used if an attack develops. There is evidence that malathion and diazinon, both as dusts and sprays, are also effective. Nicotine sprays have been used but are liable to stain the mushrooms. Mixing *gamma*-BHC with the compost as suggested for cecids is also likely to control them.

Less is known about the susceptibility of red pepper mites to the various insecticides. Pyrethrum and *gamma*-BHC sprays appear to affect them, but control is difficult because, even if exposed mites on the beds are killed, the infestation may soon be replenished by more mites coming out of the compost.

SPRINGTAILS

The very small creatures known as springtails are wingless, and have a characteristic appendage at the tip of the abdomen which can be struck violently downwards and thus enables them to jump. When not in use this appendage is held by a catch beneath the abdomen. Springtails are common in the soil and in decaying vegetable matter in damp shady situations. They have been found in manure, and thus could cause infestations of compost, and they could also infest beds in glasshouses from the soil. Under favourable conditions some species develop populations of enormous size, and it was once reported that springtails swarming on a railway track in Switzerland had halted an engine.

Several species found in mushroom beds have been named, including *Achorutes armatus*, *Proisotoma minuta* and *Xenylla mucronata*. *A. armatus* is about $\frac{1}{16}$ in. long and varies from silvery or greenish grey to dark bluish black in colour. It occurs widely on damp soil, dead leaves, under bark, on pools of water, and amongst fungi, and appears to be the commonest injurious species. Sometimes it occurs in great numbers and assembles in carpets, and even heaps on the beds and floor, from which habit it has earned the name of

"gunpowder mite". It excavates small pits in the stalk and cap of mushrooms, which are dry in contrast to the moist ones made by tyroglyphid mites. It also bores small oval openings leading to tunnels throughout stalk and cap, and when extensive this damage may cause the stalk to split (see Plate XV). The mycelium is also attacked and buttons invaded and killed; occasionally springtails have been known to cause total crop failures.

Control. Springtails are said to be killed at temperatures of 135–140 F, and control is generally obtained by efficient composting, though occasionally infestations develop, either from the soil in glasshouse beds, or in beds which have not reached sufficiently high peak heat temperatures. *Gamma*-BHC is effective, and dusting the beds or mixing *gamma*-BHC dust with the compost as recommended against cecids should give control. *Gamma*-BHC spray can be used as an emergency measure where an attack has been allowed to develop. Dusts and sprays of malathion or diazinon also appear to be effective.

EELWORMS

In addition to the well known parasites of green plants, there are many other eelworms which live in association with the soil and decaying organic matter. Some feed on fungi, others on bacteria, while some are predatory on other eelworms. Since manure and compost are likely to have eelworms of these kinds, they are of importance in relation to mushroom culture. Eelworms are generally only visible with the aid of a microscope, and are all slender, colourless creatures about $\frac{1}{25}$ in. in length, swimming with eel-like motion when in water.

At present only a few species are known with certainty to be pests of the mushroom: the most important is probably *Ditylenchus myceliophagus*. One of the first known cases in Britain of *Ditylenchus* infesting mushroom beds was in Surrey in 1950. Since then an appreciable number of infestations has been identified, though an attack by eelworms recorded over 50 years ago may quite possibly have been by this species.

It is undoubtedly responsible for the disappearance of the mycelium, and infestations generally occur in patches which gradually enlarge, usually becoming noticeable in the second or later flushes but sometimes in the first. In these patches the compost becomes dark and over-moist, it tends to sink and usually has a foul pungent smell. Buttons may turn brown and die; crop production falls and very serious losses can occur. With heavy attacks, eelworm populations of two or three million or more in $\frac{1}{4}$ lb of compost (a large handful) are not uncommon. Once an infestation has occurred it is very difficult to eradicate, as it can be carried from crop to crop through eelworms persisting in crevices in woodwork.

Under dry conditions the eelworms can assume a quiescent resting stage, and they have been known to revive after two years storage in dried compost. Although evidence that they can effectively survive long periods of desiccation needs strengthening, the danger of allowing infested debris to blow about is evident, and especially of leaving any traces of it on the composting site.

Sometimes a grey mould grows over the surface of affected patches and this was at first thought to be the cause of the crop failure ("*Cephalothecium* disease"), but this has been shown to be a predatory fungus, *Arthrobotrys*, which traps the eelworms in noose-like loops of hyphae.

Another eelworm, *Aphelenchoides composticola*, was shown in 1955 to be capable of causing similar damage to mushrooms, and since then other *Aphelenchoides* species which will attack mushroom mycelium have been recognized. In several cases an *Aphelenchoides* species has been the dominant one in large populations associated with loss of crop. On the other hand it is not infrequently found in small and apparently unimportant numbers in mushroom beds, and it is not known what conditions allow the eelworms to increase to dangerous levels. The subject had been complicated by difficulties in identification. The source of these eelworms is not known with certainty; they are probably most often introduced with the manure, but could probably also be present in casing soil. *Aphelenchoides* species have also occasionally been found in small numbers in unused peat.

Eelworms reproduce by laying eggs and the young resemble the adults, increasing in size with each moult. They breed at a very high rate; for example, in one experiment 15 *Aphelenchoides* gave rise to about three million individuals in six weeks.

Other eelworms, e.g., species of *Aphelenchus* and *Diplogaster*, occur widely and since they will feed on fungi may be of potential importance. Others again which do not apparently feed on fungi may be of significance, if only indirectly, and examples are the many species of *Rhabditis* which often occur in the compost, and sometimes in small numbers in unused peat.

Occasionally when peat is used with chalk as casing material *Rhabditis*, either from the compost or from the peat, develops populations of such size that they are obvious to the naked eye. When very abundant, larval stages of these eelworms may leave their overcrowded quarters by moving to the higher parts of the bed, such as lumps of casing and mushroom buttons, where they writhe round one another forming glistening, waving spires. These have the appearance of fly larvae but are composed of scores of intertwined eelworms, which by clinging to passing insects are carried to fresh places. This phenomenon may or may not be associated with lowered crop yields. The waste products of the eelworms, and of associated bacteria which form their usual diet, perhaps have a harmful effect on mushroom growth, but the subject needs further research.

Control. Where an attack by eelworms has been diagnosed little can be done immediately apart from cutting out and destroying affected patches, taking a generous margin of apparently healthy bed from around each area. The ease with which eelworms can persist in woodwork has been pointed out, and rigorous sanitary measures are necessary to prevent the infestation from becoming established on the premises. Heat appears to be the most effective means of control, for experiment shows that dipping infested woodwork in cold baths of nematicides, such as 2 per cent cresylic acid or solubilized xylenol at 0·4 per cent, cannot be relied upon to kill all the eelworms. American work on the temperature exposures necessary to kill *Ditylenchus myceliophagus* from mushroom beds has shown that the active eelworms under humid conditions die at once at 122°F and at 113°F survive for 30 minutes; but the resting stages under dry conditions are more resistant to heat, and they can survive 24 hours at 122°F, and require 131°F for three hours, 149°F for one hour, or 167°F momentarily to kill them.

Some growers have adopted the practice of cooking out, whereby with the aid of braziers, gilled tubing or injection of steam, the temperature of

the beds before emptying out is raised to 135–160°F for about 12 hours. This achieves a high degree of disinfection and has the advantage that risks of spreading eelworms on fragments of spent compost are minimized. Where this cannot be done, special care must be taken to prevent the carriage of infested compost to other parts of the site while the beds are being cleaned out. The bed boards and boxes must then be thoroughly cleaned and dipped for four or five minutes in boiling cresylic acid type sterilizer or formaldehyde. It is more difficult to deal satisfactorily with permanent wooden structures in the house, and these should be thoroughly sprayed with formaldehyde, cresylic acid type sterilizer, pentachlorphenol, solubilized xylenol, or painted with creosote. It may sometimes pay, especially when the woodwork is old and spongy, to replace it by tubular or angle iron supports.

It is difficult to say whether the boiling of bed boards or trays should be followed as a precautionary routine. Such a drastic and time-consuming process is probably unnecessary for the tray grower who uses a peak heat room, in which steps can be taken to ensure that high temperatures are reached in all parts of the chamber (see page 24). Cool spots can persist in the compost during peak heating, and experience suggests that it is wise to allow a considerable margin of safety by aiming at a temperature of at least 130°F, or better still 140°F for something like 12 hours.

It is frequently more difficult for the shelf grower to achieve peak heats sufficient to free the compost from eelworms before spawning. For example, the upper beds can often be raised to 140°F, while the lowest bed exceeds little more than 120°F which even for 24 hours might not be adequate. Anything which can be done to increase the temperature of the lower beds and circulate the hot air in the house is worth while.

Since eelworms may also be introduced with soil and peat, it is preferable that these casing materials should be steamed. The composting site should have a smooth surface which can be well cleaned, and after cleaning should be washed down with 5 per cent formaldehyde or cresylic acid type sterilizer.

MINOR PESTS

Woodlice

Woodlice normally inhabit decaying wood, and may become pests of mushrooms in outdoor beds, in glasshouses or makeshift buildings near their breeding places. Species such as *Oniscus asellus*, *Porcellis scaber* and *Armadillidium vulgare* have been recorded as causing injury by eating irregular holes in the caps. Woodlice are active at night, hiding by day under straw coverings or in crevices in soil or walls.

Pyrethrum or 5 per cent DDT dusts, lightly dusted over the beds and blown into crevices where woodlice may hide, are generally effective. Poison baits based on Paris green and bran are undesirable on mushroom beds.

Millepedes

Millepedes are long, slender creatures with very numerous legs, and many kinds curl into a flat spiral when disturbed. Three species are known to damage mushrooms, the spotted millepede *Blaniulus guttulatus*, which is small and pale yellowish white in colour with a row of reddish spots along the side; and the two snake millepedes *Choneiulus palmatus* and *Cylindroiulus*

britannicus, which are larger and pale fawn or brown with a row of darker spots along each side. They eat holes into the stalks near ground level, and these sometimes extend deeply into the tissues. Attacks are most likely on crops grown in floor beds in glasshouses though damage is uncommon. They are easily controlled by light applications of *gamma*-BHC dust.

Slugs

Slugs cannot invade most types of mushroom house, but they may be important pests on outdoor beds and in such situations as damp cellars. They eat large irregular cavities in stalk and cap, sometimes devouring the greater part of a mushroom. The marks made by their rasp-like tongues are similar to damage by mice, but the presence of slugs is generally betrayed by glistening slime trails.

Slugs are usually few in number and collection by hand at night is often adequate. If preferred, poison bait made with 1 part of powdered metaldehyde well mixed with 25 30 parts of dry bran can be tried. As metaldehyde is poisonous to human beings, it should not be put directly on the beds, but close by them in small heaps of about half a handful. The heaps should be two or three yards apart and each protected by a piece of tile or board sufficiently raised to allow slugs to crawl beneath. Affected slugs should be collected and destroyed. One treatment will probably clear a building, but it might have to be repeated after a week or so out of doors.

NOTES ON INSECTICIDES AND THEIR USE

The insecticides used in the control of mushroom pests are potent and a few are very poisonous, and it is essential that they should be used strictly according to the maker's instructions. Quantities should always be properly measured and evenly distributed, since carelessness may lead to damage to the crop and possibly risk to the consumer. Insecticides can be appled as dusts, as liquid or dispersible powder formulations for mixing with water for spraying, or as aerosols, smoke generators, and concentrates for atomizing. As a rule application by means of a concentrate for atomizing is considerably cheaper than by other methods.

BHC and gamma-BHC

Both BHC and *gamma*-BHC are widely used against mushroom pests and are effective against sciarid flies, springtails and several species of mites. The term BHC is used to describe a crude or technical mixture of isomers, of which one only, namely *gamma*-BHC (lindane) has any marked insecticidal properties. BHC (the crude mixture) has a distinctive smell, and may impart a musty or earthy taint to some crops and cause injury to others, though it does not have this effect on mushrooms. *Gamma*-BHC is much less likely to cause tainting or injury to crops and since formulations of *gamma*-BHC are readily obtainable at very little extra cost, they should always be used, and not BHC, in mushroom production.

BHC when mixed with the compost may check and reduce the mushroom crop, but this is unlikely to be serious if *gamma*-BHC is used provided the recommended rate is not exceeded. If the spent compost containing ordinary BHC is used as manure, potatoes and root crops may be tainted, and cucumbers and related crops may be injured, but these risks are much reduced if *gamma*-BHC is used.

Gamma-BHC is available in all forms for application. Dusts containing 0·45 per cent *gamma*-BHC are usually applied at ½–1 lb per 1,000 sq. ft of bed area, and sprays are used at about 0·01 to 0·025 per cent *gamma*-BHC (e.g., about ¾–1½ oz of 25 per cent wettable powder per 10 gal water). Smokes and concentrates for atomizing should be used according to the maker's instructions. The beds should be picked as hard as possible before any application of insecticide.

DDT

DDT is a potent, slow acting and still more persistent insecticide than *gamma*-BHC, and is effective against sciarid flies and their larvae, but not against mites or springtails. It may possibly be absorbed by mushrooms, and its use on the beds or in compost is not recommended without reserve. In emulsion form and at a relatively high concentration of about 0·5–1·0 per cent, it is probably useful as a spray around ventilators and doors to kill incoming flies.

Aldrin

Mixing aldrin dust with the compost has been advocated, and this would obviate risks of tainting when spent compost is used as manure. But although aldrin is effective against many of the insects killed by *gamma*-BHC, little is known of its value for the control of mushroom pests, while there is evidence that it can reduce the cropping of mushrooms.

HETP and TEPP

Both HETP, which is a mixture containing TEPP, and TEPP itself are available as liquid formulations for spraying. They are organo-phosphorus insecticides and are extremely poisonous, and for this and other reasons, less dangerous materials are generally preferred for use in mushroom houses. Their use is governed by The Agriculture (Poisonous Substances) Regulations, which require among other things that special protective clothing must be worn as specified according to the operation being carried out (see Appendix: Precautions in Use of Poisonous Chemicals, on page 66).

HETP and TEPP are non-persistent and break down in a few hours in water, and several applications may be necessary where the first cannot reach all the insects to be controlled. There is the consequent advantage that they can safely be used up to 48 hours before picking. These insecticides will kill sciarid larvae, and at about five times normal concentration (e.g., 2 fl. oz of 40 per cent TEPP to 10 gal water) have given effective control of tyroglyphid mites, though most growers will probably prefer to use the much safer and equally effective insecticide *gamma*-BHC. At this high concentration they also probably give a temporary check to cecid larvae.

Malathion

Malathion is another organo-phosphorus insecticide but it is much less poisonous than most of the others. Liquid concentrates should be handled with care, but when diluted to the normal concentration of about 0·1 per cent (2⅔ fl. oz of 60 per cent emulsifiable concentrate per 10 gal water) sprays can be applied without special precautions. Commonsense measures should of course be taken, such as removing quickly any concentrate accidentally contaminating the skin, avoiding breathing the spray mist for too long, and

washing thoroughly after use. Inhaling malathion dust is risky, and if it is difficult to avoid breathing considerable amounts, a face mask (light respirator) should be worn. Dusts in contact with the skin, however, are probably no more dangerous than *gamma*-BHC or DDT dusts. Concentrates for atomizing, low pressure aerosol containers and smoke generators should be used according to the maker's directions.

Malathion has proved particularly valuable for the control of phorid flies (see page 49), and will also kill sciarid larvae and seems effective against springtails and tyroglyphid mites. While the effects of aerosols from atomized concentrates or smokes may last for only a few days, dusts and deposits from 0·1 per cent sprays can remain effective for at least a week and probably longer. Dusting at about 3–4 oz per 1,000 sq. ft, or spraying at about $\frac{1}{4}$ pt per sq. yd probably gives useful protection against light attacks, but to counter severe attacks of pests in the casing, larger quantities of spray would be needed. A 5 per cent dust mixed with the compost at 4 lb per ton can give complete control of phorids but there appears to be a risk of depressing cropping at this rate, and 2–3 lb per ton is preferable.

There is no evidence that any of these treatments leads to appreciable contamination of mushrooms, or of any development of resistant forms of insects, though unfortunately some growers find that repeated use, at any rate of aerosols, may cause a yellowish discoloration of mushrooms. Sprays or dusts should probably not be used more often than once a week, and before any treatment the crop should be picked hard.

Diazinon

Diazinon is an organo-phosphorus insecticide, similar to malathion in its effect against pests but less safe to handle. Rubber gloves and a face shield should be worn when concentrates are handled, and any concentrate accidentally contaminating the skin should be removed quickly with soap and water. Prolonged breathing of the spray mist, aerosol or dust must be avoided, and if necessary a suitable mask should be worn. The worker should wash thoroughly afterwards.

Diazinon, used in a similar way to malathion, is effective against phorid flies, springtails and tyroglyphid mites, and it has shown promise against cecid larvae. Some growers apply 1 per cent dust at about $\frac{1}{4}$ lb per 1,000 cu. ft once a week after a watering. Sprays are usually made up to give 0·02 per cent diazinon (1$\frac{2}{3}$ fl. oz of 20 per cent emulsifiable liquid per 10 gal water). Twenty per cent concentrate is used for atomizing at 1 fl. oz per 3,000 cu. ft, and on a small scale 2$\frac{1}{2}$ per cent dust can be blown into the peak heat room at about $\frac{1}{4}$ lb per 1,000 cu. ft as a substitute for aerosol. Repeated use of diazinon aerosols may cause discoloration of mushrooms, though this seems less likely with dusts.

ROUTINE USE OF INSECTICIDES

For the reasons already given (see page 45), it is usually difficult to suggest a programme of insecticide treatments to be followed as a routine. Nevertheless, some treatments and practices may be so generally useful that under many circumstances they may become the mainstay of the insecticidal programme or part of the routine, particularly where buildings are makeshift or conditions expose crops to pest attacks.

Smokes or aerosols of *gamma*-BHC, malathion or diazinon are commonly employed at peak heat and may sometimes usefully supplement control by heat. During the important period when the spawn is running it is worth while to give protection against insects entering the building by blowing *gamma*-BHC dust over the beds at ½–1 lb per 1,000 sq. ft just after spawning and again after casing, or where more convenient by atomizing *gamma*-BHC once every 1–2 weeks. These treatments can be repeated during cropping as required. In warm weather in summer when risk of attack by flies is greater, they may have to be given more frequently; for example after spawning, before and after casing, and once a week during cropping. It is probably wise to alternate applications of *gamma*-BHC occasionally with malathion or diazinon to minimize the opportunities for resistant strains of insects to develop.

When eelworms, cecids and phorids occur, special measures of control are required (see pages 55 and 50). If attacks by phorid flies call for the use of malathion or diazinon, these can become the mainstay of the programme as they are likely to control many other pests as well, such as mites, springtails and sciarid flies.

Insecticides need to be used regularly where efficient peak heating cannot be arranged, or the premises particularly favour attacks by pests, for example, adapted or makeshift structures, outdoor beds or floor beds in glasshouses. The use of *gamma*-BHC as suggested above should become routine, supplemented or replaced where necessary by malathion or diazinon. It would also probably be an advantage to mix 0·45 per cent *gamma*-BHC dust with the compost at 20 lb per ton, which could be done when applying gypsum. Alternatively the insecticide could be sprayed into the compost as for the control of cecids (see page 50). The occasional light dusting or spraying of the outside of the compost heap with *gamma*-BHC, DDT, malathion or diazinon helps to keep down the insect population.

Crop and House Hygiene

Special attention to crop and house hygiene is always of great importance. A clean environment is essential for successful production, and fresh beds must be given every chance to produce clean crops. The elimination of pests and diseases from the beds and houses is obviously of first importance, and every effort should also be made to avoid any carry-over from one crop to the next, or the introduction of fresh troubles from elsewhere, whether on equipment, manure and other raw materials or by disregard for rules concerning entry into newly cleansed houses. Even on those rare occasions when no sign of trouble has been seen in a previous crop, there should be no relaxation in routine hygienic measures and rules of conduct for safeguarding the health of the crop.

In regard to crop cleanliness, over-ripe mushrooms and cut stumps harbour some diseases and are attractive to flies; they should not be left on the beds but removed and destroyed as soon as possible. Such troubles may also be spread from bed to bed on the workers' hands, and the removal of debris or diseased mushrooms should always be kept separate from picking

the crop. Organic debris of any kind and spent compost should never be left about, and keeping and using old manure should be avoided.

As far as possible care should be taken to see that pests and diseases are not introduced in the materials used for making the compost and casing; for example, by using fresh stable manure in preference to old, and by sterilizing soil or peat for casing. Some growers dust or spray the manure or compost heap periodically with *gamma*-BHC or DDT, and this is probably a useful general measure for keeping down the insect population on the premises.

The entry of the larger insects, such as the sciarid and phorid flies, can be checked by screening, and it is generally recommended that ventilators should be screened with copper gauze (gauge 35, mesh 40 to the inch). Though metal gauze is more expensive, it is tougher and more durable than the alternative cheese cloth. Screening may impede the rate of ventilation unless fans are used, and it is useless to try to screen against the very small cecid midges, unless special equipment is used. Sticky paper traps, hung near the lights, only catch some of the flies in the house, though they may serve as a useful indicator of the presence of dangerous pest insects.

The danger of introducing pests and diseases on the hands, clothing and boots of workers, and on tools and transport equipment should be kept in mind, and strict rules observed to prevent reinfestation of houses newly cleansed in preparation for cropping. Woodwork, especially where permanent wood structures are concerned, may be the sheltering place of pests and diseases persisting from one crop to another, despite measures to eliminate them. The value of effective peak heating and proper cleansing of houses is emphasized as a measure of hygiene, and as a means of preventing the build-up of pests or diseases from crop to crop. As a result of good practice in these matters, some growers find that it is often sufficient, especially in winter, to use insecticides occasionally, as and when pests are seen.

HOUSE CLEANING BETWEEN CROPS

Prevention of trouble is better than control, and few considerations are more important than endeavouring to give the fresh crop a clean start in a clean house. Once diseases or pests gain a footing or find a harbourage, their spread is often rapid and the consequences in crop losses disastrous, while the problem of eliminating infection may be difficult and costly.

Cooking-out

A recent development which has much to commend it is the practice of cooking-out when the crop is finished and before any spent compost, whether on shelves or in trays, is removed. The operation involves raising the temperature in the house to 160°F, and holding it at that level for 12 hours; this should effectively destroy most pests and diseases. If this is not done, there is always a risk of pest or disease being carried over through small portions of the spent compost being scattered when it is being taken from the cropping house. Destroying pest and disease *in situ* is obviously advantageous.

Two warnings are necessary. The fact that cooking-out has been done may give a false sense of security, with the result that less care than usual is taken in the disposal of the material. The operation should be considered as an additional safeguard and all the other precautions recommended should continue to be taken.

The second warning concerns the effect of cooking-out on the structure. A prolonged period of high temperature will soften timber, and if shelf supports and other internal fixtures are of wood, nails may pull out and bring about collapse and serious damage to the structure. This risk has been eliminated on one holding by the use of steel scaffolding and jacks set in position to take the weight of the shelves before the operation begins.

Removing old Beds

Spent compost should never be stacked near the growing houses and it is undesirable to use it as manure on cultivated land nearby. The best course is to sell it off the holding, and an ideal arrangement is to load the material straight from the house into the lorry that will take it away.

All tools, machinery, boots, and other equipment that may have been in contact with old material can also be a source of infection and should be cleaned thoroughly before being used to handle fresh material.

Disinfecting the House

After washing down with clean water the empty structure should next be sprayed with a strong fungicide. Materials usually employed include formaldehyde and DNC-sodium. The formaldehyde is used as a 5 per cent solution of commercial formaldehyde (5 gal in 95 gal water). DNC-sodium is used as 0·1 per cent solution which is obtained by dissolving 1½ lb of the 60 per cent material in 100 gal water.

Whichever material is used, the best method of application is by a high-pressure sprayer operating at 70 lb or more per sq. in. The whole of the inside, including floor, walls and roof, is treated in such a way that all cracks and crevices likely to harbour disease spores or pests receive some of the fungicide. Ventilators and doors may be open during the operation to enable parts of the framework normally covered to be effectively treated. After the spraying has been completed the house should be shut down and the temperature raised to 90 F for 48 hours if formaldehyde has been used. A period of 12 hours at the same temperature is considered sufficient when DNC-sodium is employed.

Spraying as described above is likely to be the most efficient method of disinfection, but when for some reason fumigation is more convenient this can also be done with formaldehyde. The method is to add 1 lb permanganate of potash to 3 pints of commercial formaldehyde for each 1,000 cu. ft to be treated. The reaction from this mixture is usually violent and the operator should leave the house immediately the materials come in contact.

Portable shelving can be treated with either formaldehyde or DNC-sodium at the dilutions given above. Treating one side of the side and bottom bedboards between crops with an approved type of creosote (see British Standard 144 of 1954), sometimes thinned with 10 per cent of petrol, is also practised; the treated side is manipulated so that it is on the outside of the new bed every time.

Trays can be immersed completely in disinfectant and this is undoubtedly the most efficient method of treatment, though it takes time. On some holdings, an elaborate bath has been constructed through which the trays are carried on conveyors immersed in the sterilizing liquid. Where the liquid is heated to boiling point, and the trays immersed in it for 4–5 minutes, this is

an extremely effective combination which leaves little to chance. It is especially recommended if an attack by eelworms has occurred (see page 56).

Paths and roadways connecting the houses should be sprayed with one of the fungicides mentioned. This, however, can only be really effective if, as recommended, the paths and roads are made of well-finished concrete.

Precautions in Use of Sprays

Goggles and rubber gloves should be worn when formaldehyde is being applied, and the operator should remain in the building no longer than is necessary (see Plate XVI). DNC-sodium is a very dangerous material, and toxic effects follow its inhalation as a spray, absorption through the mouth, or from contact with the skin; its use is governed by The Agriculture (Poisonous Substances) Regulations, which require among other things that specified protective clothing must be worn, and the other precautions and obligations laid down in these statutory regulations must be observed (see Appendix: Precautions in Use of Poisonous Chemicals, on page 66).

Manurial Value of Spent Compost

WHEN the time comes to empty the growing houses, the spent compost and casing material has to be disposed of. This is sometimes a problem for the grower, because in the interests of hygiene it is undesirable to keep compost that may be contaminated with pests or diseases of mushrooms, on or near the mushroom farm. On the other hand, the material is a suitable organic manure for use on many crops. Spent compost, like other bulky organic manures, is variable in composition, due mainly to the amount and kind of casing material present, but also depending on the type of material from which the compost was made, the quantities of nitrogenous boosters added, and the extent of the cropping period. It contains useful amounts of the main plant nutrient elements, and this respect some idea of its range of composition can be gained from Table II, which gives in round figures the analysis of a few samples in comparison with horse manure.

TABLE II

Manurial Value of Spent Compost

Type of Material	Analysis of Fresh Undried Material		
	N	P_2O_5	K_2O
	lb/ton	*lb/ton*	*lb/ton*
Horse manure (fresh)	12	5	12
Spent horse manure compost (excluding soil)	17	6	20
Spent horse manure compost (including soil)	9	3	10
Spent synthetic compost (excluding soil)	26	13	9
Spent synthetic compost (including soil)	13	7½	4½

The value of spent compost as a manure is being studied at Stockbridge House Experimental Horticulture Station, Cawood, Yorkshire. Trials have been in progress for several years and a number of different crops have been grown. The results so far indicate that under the conditions of soil and cropping at this Station mushroom compost has proved superior to several bulky organic materials tested and about equal to farmyard manure. However, the organic matter in spent compost is different from that in farmyard manure, and hence its action on the physical condition of soils may not be the same. In general, the organic matter is more decomposed than in strawy manure, and it may, therefore, be less effective for opening heavy soil or for preventing capping on soils subject to this trouble.

There are certain drawbacks in the use of spent mushroom compost which it is important to bear in mind, more especially where repeated heavy dressings are given. Materials used in disease and pest control may occasionally be present in sufficient amount to be harmful to crops to which spent compost is applied. For example, BHC may cause tainting of root crops, DDT is very toxic to cucumbers and related crops, and copper sulphate in quantity can be harmful to many crops.

Substantial amounts of BHC or *gamma*-BHC are often added to compost as a routine treatment, and when compost so treated is spread on land at normal rates of application, the equivalent of ½–1 cwt or more per acre of a 5 per cent BHC dust may be included. The risk of tainting vegetable crops is reduced when *gamma*-BHC only is present, but it would probably be inadvisable to crop with potatoes or carrots for canning within 18 months of dressing with compost containing a quantity of *gamma*-BHC. It is also dangerous to use compost containing crude BHC on cucumbers and related crops, because of the risk of leaf damage, but the *gamma* form should not prove harmful unless it comes in direct contact with the leaves.

Potential users of spent compost should therefore ascertain whether materials have been added which might have adverse effects on crops. As new insecticides are developed and included in composts, users of the spent material should keep themselves informed regarding changes in these materials and possible effects on their crops.

Now that peat-chalk casing mixtures are in common use, many batches of spent compost will contain relatively large quantities of lime. An application of 20 tons of spent compost per acre may add approximately 1 ton of chalk to the land. Where lime is needed, this could be an advantage; but on some other soils there may be serious disadvantages, since the addition of large quantities of lime with organic matter can lead to micro-nutrient deficiencies in sensitive crops.

Spent compost also contains relatively large quantities of soluble salts, and particularly when compost is applied regularly to glasshouse soils the soluble salts would aggravate an already unsatisfactory position. One of the problems in glasshouse soil management is the removal of excess soluble salts.

Experience with spent compost shows that problems in its use are most likely to arise in a serious form under glasshouse conditions, and for reasons already given it is most inadvisable to use it on holdings where mushrooms are being grown. When spent compost is to be used as a manure, the nature of the soil and of the crops to be grown should be taken into account, but apart from the risk of adverse effects on sensitive crops from over-liming on

some soils, and of tainting root crops with BHC (particularly the crude product), the objections mentioned are not likely to be of much practical consequence with open-land cropping.

On balance, if the limitations are kept in mind and precautions taken where necessary, spent mushroom compost compares favourably with other bulky organic manures as a source of organic matter particularly for open land, and it can be used successfully for a variety of field crops. There are many thousands of tons of this material available to farmers and market gardeners to whom its manurial value and relatively low cost should commend it. It has also proved useful as a bulky top dressing for sports turf, particularly for the fine turf of golf and bowling greens. For this purpose it should not contain either soil or free lime, and the screened material should be applied in fairly dry condition, at the rate of several pounds per square yard, and brushed or harrowed into the turf. In addition to these large-scale uses, spent compost should have possibilities as an organic manure for private gardens on account of its ease of handling and simplicity of use, whether for digging in or top dressing flowers, fruit and vegetables.

Selected Further Reading on Mushroom Growing

Books

Mushroom Growing Today. F. C. Atkins, third edition. Faber and Faber, 1956.

This Mushroom Business. F. C. Atkins. Faber and Faber, 1959.

Mushroom Growing. R. L. O. Jackson. English Universities Press, 1951.

Commercial Mushroom Growing. M. H. Pinkerton. Ernest Benn, 1954.

Modern Mushroom Cultivation. A. A. Richards. W. H. and L. Collingridge, 1954.

Periodicals

MGA Bulletin (monthly). Published by Mushroom Growers Association, Agriculture House, Knightsbridge, London, S.W.

A.M.I. News (monthly). Published by American Mushroom Institute, V.F.W. Building, Kennet Square, Pa. U.S.A.

Mushroom Science I, II and III, the Proceedings of the First, Second and Third International Conferences on Mushroom Science, which are held at three-yearly intervals. Obtainable from Mushroom Growers Association, London, S.W.1.

MGA Library

The Mushroom Growers Association, Agriculture House, Knightsbridge, London, S.W.1., have an extensive library of books, papers and pamphlets on all aspects of mushroom cultivation.

Appendix

PRECAUTIONS IN USE OF POISONOUS CHEMICALS

Some of the chemicals mentioned in the text are relatively safe to use, but others are very poisonous. As a general practice, whenever chemicals are used, read and follow the precautionary advice on the label.

The more dangerous poisonous chemicals, such as DNC-sodium and TEPP(HETP), are included in The Agriculture (Poisonous Substances) Regulations, which are statutory regulations designed to protect agricultural workers by ensuring, among other things, that they are supplied with and use the protective clothing specified to be worn. The obligations of employers and workers, and the jobs for which protective clothing must be worn are also set out.

Users of chemicals, whether subject to the statutory regulations or not, are strongly advised to read both the Ministry's leaflet APS/1, "The Safe Use of Poisonous Chemicals on the Farm", and the special leaflet "The Use of Chemicals by Mushroom Growers", obtainable free from the Ministry of Agriculture (Publications), Ruskin Avenue, Kew, Richmond, Surrey.

Official approval has been granted to a number of proprietary brands in most of the groups of insecticides mentioned in this bulletin. Approval is indicated on the containers by the mark shown above. A list of approved products may be obtained on application to the Ministry at the address mentioned above. It is recommended that approved products are used wherever possible.

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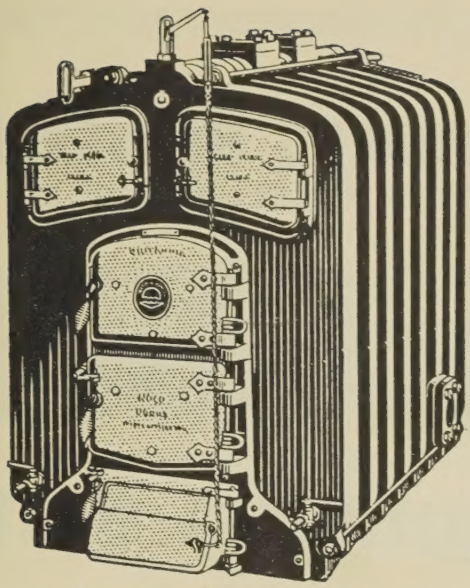

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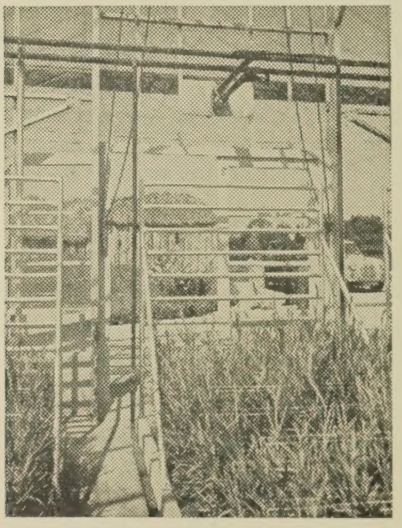

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